FINAL
SOIL SAMPLING RESULTS AND PRELIMINARY RISK ASSESSMENT FOR THE NORTH RIDGE ESTATES SITE KLAMATH FALLS, OREGON

Prepared by:

D. Wayne Berman, Ph.D.
Aeolus, Inc.
751 Taft St.
Albany, CA 94706

September 28, 2004

TABLE OF CONTENTS

APPENDIXES

1. EXECUTIVE SUMMARY

This report presents results from the analysis of asbestos in soil samples and samples of associated asbestos-containing debris (ACM)[1] collected at the North Ridge Estates Site in Klamath Falls, Oregon. The report also presents a preliminary evaluation of potential exposures to asbestos that may be released when site soils or ACM are disturbed and provides a conservative evaluation of potential risks to human health associated with such exposures.

The objectives of this preliminary risk assessment are to:

1. assess the need for immediate (versus long-term) action to protect public health at the site;

2. identify and focus issues most relevant to assessment of risk at the site; and

3. identify data gaps and focus further study at the site that will be suitable for supporting final decisions concerning a permanent remedy.

A summary of conclusions and recommendations for the three objectives of this report are each addressed separately below. These are then followed by a summary overview of the findings of each of the sections of the main body of the report.

Assessing the Need for Immediate (Versus Long-Term) Action

With one exception, the results of the risk assessment presented in this report indicate that risks posed by the presence of asbestos at the North Ridge Estates Site are sufficiently low so that immediate actions to reduce them are not warranted. Thus, taking the time required to complete site characterization and an assessment of risks that are adequate for supporting the required risk-management decisions for the site will not pose an unacceptable risk. It is therefore recommended that such investigation and analysis be completed in a timely manner so that decisions concerning a permanent remedy for the site can be based on sound technical information.

The one exception involves the need to limit opportunities for exposure to amphibole asbestos-containing ACM. Any steam-pipe insulation that is exposed at the surface of the site should be encapsulated or removed.

Identifying and Focusing Issues

The discussion of issues is divided into general conclusions and recommendations.

[1] ACM means "asbestos containing material" and some of the construction-related materials observed as debris in stie soils is composed of ACM.

The relevant conclusions of this study can be summarized as follows:

- the vast majority of asbestos observed at the North Ridge Estates Site is chrysotile. Although it is known that amosite (an amphibole asbestos) is associated with the steam-pipe insulation that exists at the site and debris containing such insulation was observed in three small, isolated areas of the site (which have been cleaned up), amosite asbestos structures were observed only rarely in samples collected and analyzed at the site;

- for residents who might walk, run, bicycle, rototill, or ride ATV's at the site, such activities are unlikely to present unacceptable risks, as long as the opportunity for exposure to amphibole asbestos-containing soils or ACM (e.g. steam-pipe insulation) remains limited. For some of these pathways (including ATV riding in particular), completion of a more sophisticated (less extreme) assessment would provide an improved indication of the upper limits to risk posed by asbestos exposure associated with this pathway;

- children who play and residents who garden in site soils (even in hot spot areas where the highest concentrations of ACM were observed) are unlikely to be exposed to asbestos at levels posing an unacceptable risk, as long as the opportunity for exposure to amphibole asbestos-containing soils or ACM (e.g. steam-pipe insulation) remains limited;

- in general, for areas in which the concentrations of asbestos in the soils themselves are low, removing visible chrysotile-containing ACM (so that the mass fraction of any remaining ACM is below 0.3%) should render soils generally suitable for the kinds of common activities considered above. Even if the remaining ACM were to completely degrade, the resulting asbestos concentrations in the soils would not be adequate to pose an unacceptable risk;

- the handling of pieces of chrysotile-containing ACM (as long as they are not intentionally abraded by cutting, sanding, or scraping) should not pose an undue concern even though risk estimates attendant to this exposure pathway are the least certain of all of the exposure pathways evaluated. At the same time, it appears that activities causing chrysotile-containing ACM to be intentionally abraded should generally be avoided;

- the intentional abrading of amphibole asbestos-containing ACM (by cutting, sanding, or scraping) should be avoided and even occasional handling of amphibole asbestos-containing ACM should be minimized;

- future construction conducted at the site should not pose an unacceptable risk to local residents, even if required measures to control nuisance dust are ignored. This remains true even if such construction were to be conducted in hot spot areas containing the highest observed asbestos concentrations (as might occur, for example, if such hot spots were to be remediated);

- future construction conducted at the site should not pose an unacceptable risk to workers as long as they practice the measures required to control nuisance dust and as long as the extent of amphibole asbestos contamination remains limited; and

- although completion of a more sophisticated (less extreme) assessment would provide an improved indication of the upper limits to risk posed by asbestos exposure during construction in areas where amphibole asbestos may be encountered at the site, use of appropriate respiratory protection should be considered for workers who disturb ACM containing amphibole asbestos for any extended period of time.

Given the results of this study, the following is recommended:

- if there is a need to reduce the uncertainty bounds for the risk estimates provided in this study for pathways in which moisture content affects dust generation, a small number of moisture content measurements could be collected in surface soils and shallow subsurface soils (spaced out over varying conditions of the year) to improve the precision of the moisture content estimates employed in the exposure modeling;

- to the degree that an improved estimate of the bounds for risks posed to residents at the North Ridge Estates Site would provide improved support for decision making at the site, it is recommended that a more sophisticated analysis of the most critical exposure pathways be completed. Depending on circumstances, risk estimates may be improved by any one or a combination of the following:

    - collecting additional measurements to develop and employ an improved estimate of the input source concentration of asbestos appropriate for each pathway of interest (see additional discussion of data gaps below);

    - collecting additional measurements at the site or in the laboratory to provide improved estimates of the input values of other model parameters that affect the estimation of exposure and risk;

    - developing or adapting more sophisticated models that better represent the actual exposures of interest (rather than representing exposures that are known to be greater than the actual exposures of interest); and/or

    - conducting sensitivity analyses and/or Monte Carlo analyses to better gauge the relative importance of the various factors affecting exposure and to derive more quantitative upper bound estimates of risk.

- due to the particular hazard posed by the presence of amphibole asbestos-containing ACM (e.g. steam-pipe insulation), it is recommended that sufficient observations and measurements be collected to adequately identify the locations of such materials at the site and actions be implemented to assure that exposure to such materials are adequately minimized. Thus, for example, a plan should be implemented to address all exposed ends and/or detached segments of steam-pipe lines at the site;

- to assure that soils remain acceptable for unrestricted use in areas where asbestos concentrations are low in the soils themselves, it will be necessary either to further refine risk calculations and devise an improved target or to remove chrysotile-containing ACM from soils that might be contacted so that the mass fraction of such material is reduced below 0.3% by weight. Also, a procedure needs to be devised for determining whether the residual concentration of ACM that remains in surface soils following the recent removal action (or any future removal actions) in fact achieves whatever target residual level is ultimately established; and

- other soils or bulk media containing ACM at the site should also be stabilized and isolated or remediated so as to minimize human contact to the asbestos contained within.

Identifying Data Gaps to Focus Further Study

The identification of data gaps to focus further study is divided into general conclusions and recommendations.

The relevant conclusions of this study can be summarized as follows:

- the existing data used to support this study appear adequate for supporting a conservative, bounding analysis of chrysotile exposure and risk at the site. However, additional sampling and analysis may be required, if there is a need to conduct a more sophisticated assessment of risks to better address outstanding issues regarding risk levels estimated for the specific exposure pathway evaluated in this study; and

- due to the greater potency assumed for amphibole asbestos relative to chrysotile, to support a final remedy based on the exposure pathways evaluated, it may be necessary to further bound the low concentrations of amphiboles that were detected and further refine the site model to assure that potential amphibole asbestos hot spots are adequately identified and addressed;

Given the above, recommendations for addressing potential data gaps are summarized as follows:

- due to the substantial uncertainty associated with several input parameters to the model involving intentional abrading of ACM (unless additional data become available from EPA), a small, bench-scale simulation is recommended to better characterize the risks associated with this pathway;

- for areas of the site where additional information is needed to better inform risk-management decisions (i.e. to determine the need for, identify, and select among options for a permanent remedy), it is recommended that additional, focused sampling and analysis be conducted to better define the areal and vertical distribution of ACM at the site to (for example):
    - o better characterize the rate at which ACM may continue to surface due to uplift from freeze-thaw cycling, erosion from water flow, or transport due to the activities of burrowing animals; and
    - o better support more sophisticated analyses of specific exposure pathways to refine exposure and risk estimates.

Summary of Sampling and Analytical Results

To support this study, eighteen soil samples were collected and analyzed for the presence of asbestos. These samples represent background conditions, general (area-wide) conditions over the occupied portions of North Ridge Estates, and areas of concentrated ACM (hot spots). Thirteen suspected ACM samples were also separated from these soil samples and separately analyzed for asbestos. The ACM itself was also weighed to determine the mass fraction (percentage weight) that the separated ACM represented in the original soil sample.

The data collected to support this study were also supplemented with data collected by the U.S.EPA. The U.S.EPA data set contains 12 composite soil samples, which were collected, prepared, and analyzed in an identical manner to the treatment of samples in this study (except that the ACM components of the U.S.EPA samples were not separately analyzed). The U.S.EPA composite samples were constructed from component samples collected on specific residential lots in a manner designed to provide conservative (high) estimates of asbestos concentrations that might be encountered by residents on their own property.

A single asbestos structure was observed among the soil components of the 10 samples collected in the current study to represent general surface soils at the site. Significantly higher numbers of asbestos structures were observed in the soil samples taken from hot spot areas (containing concentrated ACM). ACM was separated both from samples taken to represent general surface soils at the site and from samples taken in hot spot areas of concentrated ACM. Substantial concentrations of asbestos were observed in ACM isolated from both kinds of samples. Moreover, the range of concentrations of asbestos in the ACM components of hot spot samples do not vary substantially compared to the range observed among the ACM components of general (area-wide) surface samples. However, the weight of ACM compared to the weight of the total soil sample was substantially higher in all samples taken from hot spots than from samples collected to represent general surface conditions.

The range of asbestos concentrations observed in the soil components of samples collected by the U.S.EPA are not substantially different than the range of concentrations observed among the samples collected in the current study to represent general surface conditions. In fact, the upper bound estimates of concentrations derived from samples in the current study adequately bound the maximum concentrations observed among the U.S.EPA samples.

With the exception of nine amosite structures observed in a single sample, all of the asbestos observed among the samples collected in the current study were chrysotile. The single sample containing the amosite was collected from a hole in a foundation at an identified “hot spot.” Among the U.S.EPA samples, a single amosite structure was observed in each of two samples. Unlike the amosite structures detected in the current study, however, both of the amosite structures detected among the U.S.EPA samples were too short to be included in the range of structures generally considered to contribute to biological activity or risk.

Amosite is an amphibole asbestos type and amphibole asbestos (structure for structure) is believed to present a greater hazard to human health than chrysotile. Therefore, to assure that this study remains conservative in a health protective sense, the risks attributable to chrysotile and amosite are both explicitly considered in this risk assessment.

The quality of the data collected in the current study to characterize asbestos concentrations in soils at the North Ridge Estates Site was evaluated and indicates that these data can be considered reliable and reproducible. It was also shown that asbestos concentrations in site soils in areas remote from areas with high concentrations of ACM are generally low and consistent. In contrast, asbestos concentrations in soils associated with areas of concentrated ACM (hot spots) contain significantly higher concentrations of asbestos. Asbestos concentrations in the ACM itself appear to vary substantially. However, this is not surprising as both the types of ACM and the relative degree of weathering of the ACM vary from location to location at the North Ridge Estates Site.

Although the data from the U.S.EPA study are employed in this assessment to supplement the data collected in the current study, these data are currently considered to be preliminary because the quality of these data have not yet been completely characterized. It is therefore possible that some of the estimates derived from these data may change slightly when the data are finalized.

Relating Asbestos Concentrations to ACM Mass in Soil

Based on the history of the site, the asbestos observed in the soil components of samples is expected to have come from degradation of the ACM in each sample. Therefore, the relationship between asbestos concentrations in soil components and the corresponding ACM components of the available samples was evaluated. A significant correlation was found to exist between the mass of ACM found in a sample and the resulting concentration of asbestos observed in the soil component of that sample.

Moreover, it appears that detectable concentrations of asbestos only occur in soils when more than approximately 1% of the mass of the sample is comprised of ACM.

Importantly, although the observation of a significant correlation between soil asbestos concentrations and ACM concentrations reinforces the current belief that the asbestos at the site originated from ACM, this correlation is not formally employed to support the risk assessment.

Evaluating Potential Exposures

Asbestos is a potential hazard when inhaled. Because asbestos concentrations above background levels were not observed during the previous study of indoor and outdoor air under ambient conditions, the current study was performed to evaluate activity-specific exposures and their attendant risks. Therefore, an exposure assessment was conducted to evaluate the airborne concentrations of asbestos that might develop when site soils or ACM are disturbed by common human activities. The residential activities evaluated include:

- walking, running, bicycling, and riding ATV's over site soils;
- rototilling, gardening and playing in site soils; and
- handling and abrading ACM.

Potential exposures due to generation of airborne asbestos from future construction activities were also evaluated.

These exposure scenarios were selected for evaluation because they are expected to contribute the most to overall, outdoor residential exposure.

Risk Assessment

To assess risk, an extremely conservative, worst-case analysis was conducted. Thus, conservative (upper-bound) estimates of asbestos concentrations in soils and ACM were derived from site measurements, upper-bound estimates of exposures were derived by using conservative input assumptions for the exposure models, and conservative risk estimates were developed by multiplying the conservative exposure estimates by conservative risk factors. In fact, risks are estimated in two ways based on two different size categories of asbestos structures using two different sets of risk factors. This was done to assure that the full range of potentially important considerations is addressed.

This analysis provides high confidence that any actual risks are less than the risks estimated in this report. Therefore, where this report concludes that a risk is within the range of risks generally considered acceptable by the U.S.EPA, the conclusion is valid because any actual risk will be even lower. In contrast, it is ***not*** valid to conclude from such a conservative, worst-case analysis that risks identified as unacceptable in fact present a current health risk. If estimated risks appear unacceptable from this type of analysis, the correct conclusion is that a more sophisticated and realistic (although still health-protective) analysis needs to be completed to assess whether actual risks are indeed unacceptable.

Due both to the differences in their relative distribution and to properly account for their relative potency, risks attributable to chrysotile and amphibole asbestos were separately evaluated. Potential risks to residents posed by disturbing asbestos in soils and ACM at the North Ridge Estates Site while conducting common outdoor activities (excluding the direct handling of ACM) are estimated to range between one in one million and three in ten thousand, depending on which of the two sets of risk factors and the type of asbestos (chrysotile, amphibole asbestos, or the two combined) that are considered.

The residential activity associated with the greatest estimated risks (excluding intentional abrading of ACM) is ATV riding, which is estimated to slightly exceed one in ten thousand. However, due to the extremely conservative manner in which these risks are estimated, it is unlikely that actual risks exceed this value. Thus, a more sophisticated analysis may be conducted as part of the final risk assessment for this site to provide an improved upper-bound estimate of the risks associated with this activity to better evaluate this expectation.

Except for direct handling of ACM (which is addressed below), none of the other risk estimates for residential pathways at the North Ridge Estates Site exceed the upper end of the risk range (one in one million to one in ten thousand) that is generally considered acceptable by the U.S.EPA when site-specific conditions are addressed.

The risks estimated for the pathway involving intentional abrading of chrysotile-containing ACM are approximately two in ten thousand. Based on these results for chrysotile-containing ACM, which represents the vast majority of the material encountered at the site, the simple handling of such ACM will not likely lead to unacceptable risks, while the intentional abrading of such material should probably be avoided. This conclusion is based on consideration both of the levels of risk estimated for this pathway and knowledge that risk estimates for this pathway are the least certain of any of the exposure pathways evaluated in this study.

The risks estimated for the pathway involving intentional abrading of amphibole asbestos-containing ACM range between one in one thousand and six in one hundred, depending on which of the two types of risk factors are considered. Thus, intentional abrading of amphibole asbestos-containing ACM should be avoided and even the handling of this material should be minimized.

Fortunately, amphibole asbestos-containing ACM appears to be encountered only rarely at the site. It is largely (if not exclusively) associated with insulation of the steam pipe that is known to be buried along a defined set of corridors at the site and has generally become exposed only in finite areas where steam pipes terminate at old building foundations or have been excavated. The three small and isolated areas where such insulation was recently observed at the surface of the site have been cleaned up. Even the single sample in which amphibole asbestos structures (in a size range that is considered to contribute to risk) were observed is consistent with this material being associated with steam pipe because, as previously described, this sample was collected from a hole in an old building foundation.

Because the hazard associated with amphibole asbestos (fiber for fiber) may be up to 100 times greater than the hazards associated with chrysotile asbestos, measures should be implemented at the site to assure that contact with amphibole asbestos-containing ACM (e.g. steam-pipe insulation) is avoided. Thus, for example, areas where steam-pipe insulation is exposed should be immediately addressed.

Risks associated with a hypothetical, future construction scenario and a hypothetical remediation scenario were also evaluated. Based on the evaluation of the exposure pathways associated with these scenarios, risks posed to residents in association with such activities range between three in ten million and three in one hundred thousand (depending on the type of asbestos and the specific risk factors considered) and should thus remain within the range potentially considered acceptable by the U.S.EPA when site-specific considerations are addressed. This remains true whether measures required to control nuisance dust are practiced during such activities or not.

Regarding worker exposures, as long as workers implement the measures required to control nuisance dust and as long as the extent of amphibole asbestos contamination remains limited, future construction activities at the site should not pose an unacceptable risk to workers. Although completion of a more sophisticated assessment would provide an improved indication of the upper limits to risk posed by asbestos exposure during extended periods of construction in areas where amphibole asbestos may be encountered at the site, risks for workers who participate in activities generating dust in such areas are estimated in the current, extremely conservative, bounding analysis to slightly exceed one in ten thousand.

2. INTRODUCTION

This report presents results from analyses of soil samples and samples of associated asbestos-containing debris (ACM)[2] collected at the North Ridge Estates Site in Klamath Falls, Oregon. A preliminary evaluation of exposures (and the attendant risks) potentially associated with release and transport of the asbestos observed in soils (or ACM) is also presented. Thus, this report compliments the study of airborne asbestos measurements previously reported (Berman 2003a), which focused on local, ambient conditions. In contrast, this report addresses concerns associated with activity-specific exposures and the attendant risks.

[2] When ACM could be isolated in sufficient quantities from specific soil samples to allow for independent analysis, both the mass fraction of ACM and the concentration of asbestos in the ACM were determined and reported.

The preliminary risk assessment presented in this report is designed primarily to:

1. assess the need for immediate (versus long-term) action to protect public health at the site;

2. identify and focus issues most relevant to assessment of risk at the site; and

3. identify data gaps and focus further study at the site that will be suitable for supporting final decisions concerning a permanent remedy.

Two sets of soil samples were collected[3]. Initially, 10 composite soil samples (and their associated ACM samples) were obtained to characterize general soil conditions around the site. These were each generated by combining 12 kg-size samples collected from locations defined using a stratified-random sampling scheme[4]. The composite samples were then supplemented with seven additional samples collected from "hot spot" locations, where high concentrations of ACM and/or particularly weathered ACM were observed in the field. These latter sampling locations were selected by the U.S. Environmental Protection Agency's (U.S.EPA's) On-Scene Coordinator.

Once collected, samples were brought back to a central location for field preparation. Field preparation of soil composites consisted of: (1) weighing each component sample; (2) combining component samples (to create the composites) and weighing again; (3) homogenizing and splitting each composite into equal halves; (4) manually separating out all visible ACM from one split of each composite; (5) sieving the remaining soil component (to pass through a 1 cm sieve); (6) weighing the coarse and fine fraction of the soil component; and (7) homogenizing and splitting the fine fraction to obtain 50 to 80 g sub-samples that were then weighed, packaged, labeled, and shipped to the laboratory for analysis.

The isolated ACM from each sample composite was also weighed and crushed (so that 100% would pass through the same 1 cm sieve), homogenized and split to obtain 50 to 80 g sub-samples that were then weighed, packaged, labeled, and also shipped to the laboratory for analysis.

Hot spot samples were field prepared in a manner identical to that described above for soil composites, except that samples were not first constructed by compositing component samples. Thus, hot spot samples were prepared by completing the equivalent of Steps 3 through 7 that are listed for soil preparation above. The ACM

---

[3] Results from the above-described sampling effort are also compared to results obtained from an independent sampling effort later conducted by U.S.EPA. The latter set of results became available only very recently.

[4] Due to the requirement that sampling be conducted expeditiously, an informal procedure was ultimately adopted for identifying sampling locations in the field that preserved the general features of the proposed, stratified random sampling scheme. The effect of any biases potentially introduced through use of the informal scheme is addressed in the uncertainty section of this document.

components derived from each hot spot were also treated identically to that described for ACM above. Details of the procedures employed for sample collection and field preparation of all samples are provided in Chapter 8 of Berman and Kolk (1997), modified as indicated in the Fast-Track Sampling and Analysis Plan (Berman 2003b) developed for this site.

Once in the laboratory, soil and ACM samples were prepared and analyzed as described in the Modified Elutriator Method (Berman and Kolk 2000). This means that samples were placed in a specially designed dust-generator to separate and concentrate the respirable fraction[5] of each sample. The respirable fraction is then deposited on a filter, weighed, and prepared by a direct-transfer procedure for analysis by transmission electron microscopy (TEM). Importantly, as indicated in the following paragraph, although the respirable fraction of the sample is isolated during sample preparation and analysis, the measurement in fact represents determination of the concentration of asbestos in the entire sample.

As has been shown (Berman and Kolk 2000), by reporting the results of samples analyzed as described in this method as the ratio of the number of asbestos structures per gram of the respirable dust that is produced, the resulting measurements reflect the concentration of asbestos that is an inherent property of the original, bulk sample. In fact, the preparation steps of Berman and Kolk (2000) are designed specifically to assure that the microgram quantities analyzed by TEM remain representative of the kilogram-sized samples collected in the field. Such measurements are thus unique among the kinds of bulk asbestos measurements that can be derived using available methods and are particularly suited for supporting risk assessment.

All samples were prepared as described in Berman and Kolk (2000) and analyzed using the counting rules of ISO 10312 (ISO 1995) with the counting rules modified to count only structures satisfying the traditional definition of a fiber (as defined in Walton 1982) and structures satisfying the dimensions of biologically active structures defined in Berman and Crump (2001). Traditionally defined fibers are generally those longer than 5 µm (micrometers), thicker than 0.25 µm, and exhibiting an aspect (length to width) ratio greater than 3. These typically satisfy the “B” counting rules of NIOSH Method 7402 (NIOSH 1989) and are henceforth termed “7402 structures”. Biologically active structures defined by Berman and Crump are generally longer than 5 µm and thinner than 0.5 µm. Such structures are henceforth termed “protocol structures.” In addition, a selected subset (20%) of samples was also analyzed for total ISO structures including those between 0.5 and 5 µm in length.

Material from 18 available soil samples (which include one sample collected at one of two “background” locations) and a total of 13 ACM samples (including two duplicates)

---

5 In this report, the respirable fraction of a sample is composed of respirable dust. In turn, respirable dust is defined as the set of structures exhibiting an aerodynamic equivalent diameter less than or equal to 10 µm, which is captured by devices designed to extract what is termed the “PM_{10}“ fraction of particulate matter. Thus, the terms “PM_{10}“ and “respirable dust” are used interchangeably throughout this document. The “aerodynamic equivalent diameter” of a particle is the diameter of a sphere of unit density that exhibits the same settling velocity in air as that of the actual particle.

have been analyzed. Results are described below. These results were then evaluated by:

1. identifying the exposure pathways by which asbestos in soils at the site may be disturbed and become airborne so that site residents or workers (receptors) may become exposed;

2. using appropriately adapted emission and dispersion models to estimate airborne *dust* concentrations to which site receptors may be exposed;

3. combining dust exposure estimates with the measurements of asbestos concentrations from site soils (source material) to derive asbestos exposure estimates; and

4. combining asbestos exposure estimates with appropriate exposure-response factors to assess risk.

The potential risks attributable to the presence of asbestos in local soils were assessed in precisely this manner, as described in the sections of this document that follow a brief background discussion.

3. BACKGROUND

To facilitate review of this document, asbestos is defined and the health effects attributable to asbestos exposure are briefly discussed below. A summary of considerations addressed in association with the measurement of asbestos is also presented.

3.1 The Definition of Asbestos

As indicated in Berman and Crump (2001), asbestos is a term used to describe the fibrous habit of a family of hydrated metal silicate minerals. The most widely accepted definition of asbestos includes the fibrous habits of six of these minerals (IARC 1977). The most common type of asbestos is chrysotile, which is the fibrous habit of the mineral serpentine. The other five asbestos minerals are all amphiboles (i.e. all partially hydrolyzed, magnesium silicates). These are: fibrous reibeckite (crocidolite), fibrous grunerite (amosite), anthophyllite asbestos, tremolite asbestos, and actinolite asbestos.

All six of the minerals whose fibrous habits are termed asbestos occur most commonly in non-fibrous, massive habits. While unique names have been assigned to the asbestiform varieties of three of the six minerals (i.e. chrysotile and two of the amphiboles, which are noted parenthetically above) to distinguish them from their massive forms, such nomenclature has not been developed for anthophyllite, tremolite, or actinolite. Therefore, when discussing these latter three minerals, it is important to specify whether a massive habit of the mineral or the fibrous (asbestiform) habit is intended.

3.2 The Health Effects Attributable to Asbestos Exposure

When disturbed by natural forces or human activities, asbestos can release microscopic fibers and more complex structures (e.g. bundles and clusters)[6] into the air and many of these structures are respirable. It is generally accepted that inhalation of such asbestos structures can lead to a range of adverse health-effects including, primarily: asbestosis, lung cancer, and mesothelioma (see, for example, Berman and Crump 2001).

Asbestosis, a chronic, degenerative lung disease, has been documented among asbestos workers from a wide variety of industries. However, the disease is expected to be associated only with the higher levels of exposure commonly found in workplace settings and does not typically result from environmental asbestos exposure[7]. Therefore, asbestosis is not addressed further in this document.

The types of lung cancers that have been attributed to asbestos exposure are similar to those attributed to smoking. Further, simultaneous exposure to asbestos and cigarette smoke tends to have a multiplicative effect on the risk of developing lung cancer (Berman and Crump 2001).

Mesothelioma is a rare cancer of the membranes that line the pleural cavity (which surrounds the heart and lungs) and the peritoneal cavity (i.e. the gut). Although there is some evidence of a low background incidence of spontaneous mesotheliomas in the general population, this cancer has been associated almost exclusively with exposure to fibrous substances (HEI-AR 1991). In most cases, this means exposure to asbestos. In rare cases, however, exposure to other fibrous substances has also been linked to the induction of mesothelioma. For example, erionite (a fibrous zeolite mineral that occurs in some volcanic tuffs) has been established as the causative agent for the high rate of mesothelioma observed in some villages in Turkey (Baris 1987).

Gastrointestinal cancers and cancers of other organs (e.g. larynx, kidney, and ovaries) have also been linked with asbestos exposure in some studies. However, such associations are not as compelling as those for the primary health effects listed above and the potential risks from asbestos exposure associated with these other cancers are much lower (see, for example, Berman and Crump 2001). Consequently, by addressing the more substantial asbestos-related risks associated with lung cancer and mesothelioma, the much more moderate risks potentially associated with cancers at other sites are also addressed by default. Therefore, the risks addressed in this document are focused on lung cancer and mesothelioma.

---

6 For concise definitions of respirable asbestos structures, see ISO (1995).

7 It should be emphasized that this site differs in two critical ways from the site in Libby, MT where asbestosis has been observed among the local population (U.S.EPA 2000a, 2001). First, exposure at North Ridge is primarily to chrysotile and none of the fibrous winchite-richterite (sometimes called soda tremolite) found at Libby has been found or is expected to be found at North Ridge. Second, it is currently believed that substantial exposures that are much larger than typical for residential scenarios may have occurred for at least a subset of the population at Libby (U.S.EPA 2001).

3.3 Considerations Associated with Asbestos Measurement

When air samples are analyzed for the determination of asbestos (see, for example, ISO 1995 or NIOSH 1989), results are reported in terms of the number of structures (of a selected range of sizes) per unit volume of air. As long as an appropriate range of asbestos structure sizes are selected for determination, such structure number concentrations are generally considered to predict risk (see, for example, Berman and Crump 2001 or IRIS 1988). In contrast to most other hazardous materials, mass concentrations of asbestos (e.g. the number of grams of asbestos per unit volume of air) have been shown to predict neither structure number concentrations nor any associated risk (Berman and Crump 2001).

Asbestos has traditionally been determined in bulk materials (primarily ACM), using a method (Perkins and Harvey 1993) that relies (at least initially) on polarized light microscopy (PLM) and that, even when confirmed by TEM, results are reported in terms of a mass concentration of asbestos (the number of grams of asbestos per unit mass of soil). However, as indicated above (and as stated in the method itself), such measurements cannot be used to predict risk. In further confirmation, a study by Berman (2000) demonstrated that PLM-based measurements of asbestos concentrations in an asbestos-containing road surface could not be related to airborne asbestos exposure concentrations (generated from vehicular traffic on the road) in any non-arbitrary fashion.

Given the above, as previously indicated, asbestos concentrations are determined in soils in this study using the modified elutriator method (Berman and Kolk 2000), which was shown to provide measurements that can be used to predict exposure and the attendant risk (Berman 2000). Among other things, this is because asbestos concentrations are reported as structure number concentrations, rather than mass concentrations.

It should also be noted that another method of reporting concentrations, the mass fraction of ACM in soils, is also discussed in later sections of this document. This is the number of grams of ACM per unit mass of soil and it is determined simply by separating the ACM from the soil in which it resides, weighing each fraction, and taking the ratio. Such measurements should be distinguished either from measurements of the mass of asbestos in the ACM itself or from measurements of asbestos (as opposed to ACM) in soil. Each is determined by a different method, reported in a different manner, and used for a different purpose.

4. ANALYTICAL RESULTS

Results from the analysis of soil and ACM samples are summarized in Table 1. The first three columns of Table 1 indicate, respectively, the sample identification number for the soil component of the sample analyzed from each specified location, the sample identification number for the ACM component (when available) of the sample analyzed from each specified location, and the location identifier. The field locations represented by each location identifier along with descriptions of the nature of the matrices sampled (for hot spot samples) are provided in Appendix A.

The fourth column of Table 1 indicates the mass fraction of ACM found in each sample. The mass fraction is equal to the mass of ACM isolated from the sample divided by the initial mass of the sample (prior to sieving or any other separation).

The fifth and sixth columns of Table 1 indicate the analytical sensitivities achieved during analysis of the soil and ACM components of each sample, respectively. Analytical sensitivity is defined as the concentration equivalent to the detection of a single structure during analysis. This is calculated as described in Equation 4.1:

$$AS = N_{str}*A_{filter}/(N_{g.o.}*A_{g.o.}*M_{PM10}) \qquad (4.1)$$

Where:

- AS is the analytical sensitivity (str/g_{PM10});
- N_{str} is the number of structures counted. To determine the analytical sensitivity (per the definition of analytical sensitivity), this value is set equal to one (str);
- A_{filter} is the effective area of the sample filter (mm^2);
- $N_{g.o.}$ is the number of grid openings counted (unitless);
- $A_{g.o.}$ is the effective area of a grid opening (mm^2); and
- M_{PM10} is the mass of respirable dust deposited on the analytical filter (g_{PM10}).

The numbers of asbestos structures of specific types that were observed during analysis of the soil component of each of the listed samples are presented in the next three columns of the table: short protocol structures in Column 7, long protocol structures in Column 8, 7402 structures in Column 9, and total structures[8] in Column 10. Counts of corresponding structure types that were observed in the ACM fraction of each sample are reported in Columns 11 through 14 of the table, respectively. Because the sets of protocol structures and 7402 structures are not mutually exclusive, the total number of structures observed in any particular sample may be less than the sum of short protocol structures, long protocol structures, and 7402 structures that are presented in the table.

Note that the numbers of short and total ISO structures (analyzed in a selected subset of samples) are not reported in Table 1. These are instead presented and discussed in

[8] In this table, “total structures” refers to the total number of structures observed that qualify as either protocol structures or 7402 structures (i.e. the total number of structures longer than 5 µm). Although a subset of samples were also analyzed for total ISO structures (which includes structures shorter than 5 µm), these structures are not considered in the data presented in Table 1. Rather they are addressed separately (see Appendix B). It should also be noted that “short” protocol structures refers to protocol structures between 5 and 10 µm in length and is used to distinguish such structures from “long” protocol structures, which refers to protocol structures longer than 10 µm. Such distinctions are important to addressing risk (See Section 5.4).

Appendix B. Short and total ISO structures are not addressed further here because there is currently no known procedure for independently relating such structures to risk. However, any potential contributions from such structures to risk are included by default in the evaluation reported herein. This is due to the manner in which risk factors are derived for the structures that are evaluated (Berman and Crump 2001).

Concentrations (in structures per gram of PM_{10}) that are estimated, respectively, for total protocol structures, long protocol structures, and 7402 structures are presented in the Columns 15 through 17 of Table 1, for structures observed in soil components, and in Columns 18 through 20, for structures observed in ACM components, from each sample[9]. The last two columns of the table present the fraction of long structures (among total protocol structures) observed in soils and ACM, respectively.

As indicated in Table 1, except for a subset of the asbestos structures observed in Sample No. 76 (nominally the soil component from “hot spot” HS-6), all of the asbestos structures observed in the samples analyzed were chrysotile. Several of the asbestos structures observed in Sample No. 76 were amosite.

It is also interesting that several of the structures exhibiting the clear morphological characteristics of chrysotile in Sample No. 76 did not exhibit a recognizable electron diffraction pattern, which suggests that they may have been subjected to high heat. In Table1, structures in Sample No. 76 exhibiting clear diffraction patterns are denoted as “confirmed chrysotile” and structures exhibiting morphological characteristics of chrysotile but no diffraction pattern are denoted as “putative chrysotile.” The sum of confirmed and putative chrysotile is represented as “total chrysotile” and it is the concentrations of total chrysotile (or total asbestos, which includes the amosite structures) that are assumed for this sample in the following evaluation of risk.

Sample No. 76 is also unusual in another way. It is surprising that (as indicated in Table 1) only a single structure is observed in the ACM component of HS-6 (i.e. Sample No. 98 and its duplicate split, Sample No. 100) when substantial numbers of asbestos structures were observed in the corresponding soil component (Sample No. 76). This is because the source of asbestos in all samples collected from the site is expected to have been the ACM in the soil: even the asbestos observed in the soil component of every sample. Thus, greater concentrations of asbestos are expected to be observed in the ACM component than in the soil component of every sample[10]. As expected, substantially greater concentrations are observed in the ACM component of all of the other samples analyzed from this site.

---

[9] Concentrations are calculated simply as the number of structures observed in a sample multiplied by the analytical sensitivity achieved for that sample. This follows directly from the definition of analytical sensitivity (see text above).

[10] ACM was typically formulated to contain asbestos at concentrations exceeding 5% by mass. In contrast, soil concentrations of asbestos likely derive from the degradation of the embedded ACM that, with few exceptions, only constitute a minor fraction of the mass of the combined material (soil and ACM) collected from any sample location.

Plausible explanations for the surprising lack of asbestos in the ACM component of Sample No. 76 may relate to the sample's pedigree and composition. This sample was collected from a hole in one of the foundations at the North Ridge Estates site (see Appendix A) and appears to contain mostly construction materials, with only limited soil. According to the laboratory (A. Kolk, private communication), the bulk of the material in this sample appears to be a fine, cementitious material (which may be a wall plaster). There are also visible pieces of putative ACM mixed within the matrix of this sample. Moreover, the composition of the corresponding "ACM" component analyzed from HS-6 (i.e. Sample Nos. 98 and 100) appears to be composed almost exclusively of the same cementitious material (A. Kolk, personal communication). These observations in the laboratory are also consistent with those in the field in which the absence of visible fibers in the "clayey or plaster-type" material reportedly suggested that this material may not in fact be true ACM (Appendix A).

It is not clear why the soil and ACM components of HS-6 were separated in the manner that they were. However, it appears that even the soil component of this sample contains relatively little soil. It may also be that separating true ACM from other artificial materials in this sample was particularly difficult and that some of the wrong materials (i.e. asbestos-free construction materials) were incorrectly assumed to be ACM during the separation process. Alternately, the primary component of these samples (i.e. the white cementitious material reported by the laboratory) may in fact contain asbestos but the asbestos may be coated with binders such that the asbestos cannot be readily recognized as asbestos during microscopic examination. This latter hypothesis is unlikely, however, given that high concentrations of asbestos structures are observed in the soil component.

Whatever the explanation for the apparent anomaly between asbestos in soils and in ACM in the material collected from HS-6, the concentrations of asbestos observed in the soil component of this sample are considered without modification in the following risk assessment (meaning that the maximum possible concentration is assumed). Thus, the manner in which this sample is interpreted is consistent with the evaluation in this report being a conservative, bounding analysis, as described below.

4.1 Data Quality

The quality of the data collected to characterize asbestos in soils at the North Ridge Estates Site was also evaluated to determine their suitability for use in supporting risk assessment and the attendant risk-management decisions. To evaluate data suitability, a number of quality control checks were performed. These include:

- analysis of blanks to test for sources of external contamination;
- analysis of the uniformity of filter deposits obtained from the elutriation of samples. This is performed to evaluate the reliability of sample preparation; and
- analysis of duplicates to test for data reproducibility.

Analyses of the consistency of asbestos concentrations observed across selected soil and, separately, ACM samples were also conducted to better determine the degree with which the set of samples collected can be considered to represent general vs. local conditions at the site.

4.1.1 Blanks

Because no fibers were detected in any of the filter lot blanks or any of the sand blanks that were analyzed in support of this project, it appears that cross-contamination or contamination from an outside source can be dismissed as concerns. Thus, such considerations are not further addressed.

4.1.2 Analysis of the uniformity of filter deposits

As previously indicated, when samples are prepared as specified in the Modified Elutriator Method (Berman and Kolk 2000), asbestos is deposited on a filter that is then prepared for analysis by TEM. When such preparation is conducted properly, asbestos structures are deposited randomly across the sample filter and the number of structures deposited is a direct function of the concentration in the original bulk sample[11]. Consequently, the chance of encountering a structure by scanning a fixed (small) area of the filter (which is how asbestos analyses are performed) is Poisson distributed[12]. Thus, repeated analyses (typically over different portions) of the same sample filter will not result in identical measurements. Rather, a distribution of structure counts will be observed (which is described by a Poisson distribution with a mean equal to the mean number of structures per unit area of the filter). For this reason, structure counts observed on different portions of the filter must be compared statistically. Thus, chi-square tests[13] (Box et al. 1978) were conducted to determine whether the deposits on particular sample filters are uniform.

---

11 The objective of depositing asbestos on the filter is to create a “uniform” deposit, which means that particles on the filter are randomly distributed. If the deposit is not uniform, particles will not be randomly distributed so that the chance of encountering a particle will not be the same across all areas of the filter. Thus, if the deposit is not “uniform,” biases may be introduced depending on the portions of the filter that are scanned during analysis.

12 A Poisson distribution is a mathematical function (like a normal distribution) that describes the variation (differences) that will be exhibited by repeated measurements of a sample around some central value (the mean) that represents the true number of particles (or concentration) in the sample. Due to uncertainty, multiple measurements of the same sample will never provide exactly the same result. In the case of asbestos structures spread over a surface that is scanned during a measurement, the Poisson distribution describes the probability of encountering specific numbers of structures over a fixed area of the surface, given a mean concentration over the entire surface.

13 Chi-square tests are mathematical tests that compare the variation observed among a set of measurements to the variation that is predicted by a known distribution (such as a Poisson distribution) to evaluate whether such measurements can be considered to be consistent (i.e. whether they can be considered to be measuring the same thing).

As required in the Modified Elutriator Method, five grid specimens are typically prepared (by direct transfer) for TEM analysis from each sample filter. Because the five grid specimens are prepared from broadly distributed sections of a filter, a test for the consistency of the number of structures observed on each of the five specimens of the filter constitutes a test of the uniformity of the deposit across the entire filter. When filter deposits can be shown to be uniform, confidence can be placed in extrapolating structure counts observed on the filter to the concentrations of asbestos in the original sample.

An illustration of the manner in which calculations were performed to conduct each chi-square analysis is presented in Table 2. In Table 2, grid specimen labels are presented in the first column. The second column indicates the number of structures observed on each grid specimen. The total number of structures observed across all grid specimens (which is simply the sum of the number of structures observed on each individual grid specimen) is also presented at the bottom of this column.

The third column in Table 2 indicates the number of grid openings scanned on each grid specimen (which is proportional to the area of the filter represented by the scan of each grid specimen). The total number scanned on all grid specimens combined is also presented at the bottom of this column. Note that, for this sample, the number of grid openings scanned on each grid specimen is the same, but this is not true for every sample.

What is required next for the chi-square analysis is to estimate the "expected" number of structures on each grid specimen. This represents the number of structures that would be encountered on the fraction of the total area (across all grid specimens) that was scanned on each particular grid specimen while assuming that structures are uniformly distributed across the total area. Thus, the expected number of structures on a particular grid specimen is calculated as the total number of structures observed (indicated at the bottom of Column 2) multiplied by the area scanned on that grid specimen (i.e. the number of grid openings indicated in Column 3) divided by the total number of grid openings scanned across all grid specimens (indicated at the bottom of Column 3). The expected number of structures for each grid specimen is presented in the fifth column of Table 2.

Note that, to facilitate such a calculation, the ratio of the number of grid openings (scanned on a particular grid specimen) to the total number of grid openings scanned (across all grid specimens) is presented as a normalizing factor in Column 4. The expected number of structures is then determined simply by multiplying the total number of structures by the corresponding normalizing factor for each grid specimen.

The test statistic for the chi-square test is then calculated as indicated in the last column of Table 2. This test statistic is the sum over the five grid specimens of the square of the difference between the observed (O) and expected (E) number of structures divided by the expected number of structures for each grid specimen. A test statistic is a value calculated from data for a parameter that is known to vary in a defined manner (described by a particular, statistical distribution), as long as the contributions to such variation are random (i.e. not attributable to a systematic cause). In this case, the indicated test statistic represents the chi-square parameter of a chi-square distribution (Box et al. 1978).

The test statistic is then compared to a critical value, which is determined for a specific level of significance (chosen to be 0.05 or 5% in this document) and an appropriate number of degrees of freedom. The critical value represents the value for the parameter of a distribution that is sufficiently different from the central value (mean) of the distribution to conclude that anything more extreme (further removed from the central value) is likely due to non-random effects. Thus, when the value of a test statistic is more extreme than the critical value of the distribution, it is appropriate to conclude that other factors have contributed to the variation observed in the test statistic. The level of significance represents the fraction of the distribution that we accept as sufficiently extreme to conclude that the behavior of the test statistic is not consistent with the behavior predicted by the distribution. It is common practice to use a significance level of 5%, which means that the random chance of encountering a test statistic more extreme than the test statistic obtained is no more than 5%. Depending on the nature of the comparison being considered, however, alternate significance levels can also be appropriate.

The number of degrees of freedom (df) in this case is equal to 4, which is one less than the number of realizations (i.e. the number of grid specimens, which is five) evaluated. At 5% significance with 4 df, the critical value for the chi-square distribution is 9.49 (Box et al. 1978). Thus, because the value of the test statistic in Table 2 (8.94) is less than the critical value, we can conclude that the counts across the five specimen grids are consistent so that the deposit on the filter can be considered uniform.

Structure counts across specimen grids from every sample in which at least 3 structures were observed were subjected to a chi-square analysis in this study. As indicated in Table 1, 11 ACM samples and 3 soil samples exhibited sufficient structures to be evaluated. Results are presented in Table 3.

Note that samples in which fewer than 3 structures were observed were not subjected to a chi-square test because the number of structures is too small for the test to be useful (the test statistic cannot fail).

In Table 3, the first column indicates the sample number and the second column indicates the sample type (soil or ACM) for the sample filter evaluated. The critical value for the chi-square distribution appropriate for each test is presented in the third column of the table. The fourth, fifth, and sixth columns of the table present, respectively, the value of the test statistic evaluated for counts of each of three different structure types (total protocol structures, 7402 structures, and total asbestos structures) that were observed on the indicated sample. The last three columns of the table indicate, respectively, whether counts of protocol structures, 7402 structures, or total asbestos structures across the five grid specimens prepared from each indicated sample can be considered to be consistent (i.e. whether the test statistic for the chi-square analysis exceeds the selected critical value).

As can be seen in Table 3, with the exception of Sample No. 91 (which will be discussed separately below), at least one (and generally two) of the three structure categories evaluated from each sample are found to be consistent across grid specimens prepared from the sample filter. It is thus apparent that the distribution of structures on each sample filter is adequately uniform to extrapolate observed counts to asbestos concentrations in the corresponding samples with confidence. In fact, in all but two of the seven cases in which a particular structure category is found to be inconsistent at the 5% level of significance, it is found to be consistent at the 1% level of significance (critical value = 13.3). It should also be noted that out of a total of 39 tests (excluding those from Sample 91, see below), one should expect 2 failures of the statistical test (5%) simply based on chance, even with no outside influences. This is an unavoidable consequence of conducting large numbers of statistical analyses.

That counts of some (but not all) of the structure categories appear to be inconsistent across grid specimens of some samples is likely due to limitations in the ability of analysts to strictly distinguish among the different structure categories. Thus, structure ambiguities may contribute to the variation in counts observed across grid specimens. This may also be why the fewest inconsistencies (only one, other than Sample No. 91) are observed among the most general category of structure (total asbestos structures). Moreover, there is no known mechanism by which structures of one size category should be randomly distributed while structures in another size category are not. Thus, given the overall evidence presented above, the results of the analysis reported here indicate that, with the possible exception of Sample No. 91, estimates of asbestos concentrations in samples analyzed can be confidently derived from the structure counts observed.

Note that the above results are also consistent with general observations concerning the uniformity of filters prepared from samples of asbestos in both air and bulk materials that are evaluated in other studies.

Sample No. 91 is the only sample presented in Table 3 for which all three structure categories appear to be inconsistent across specimen grids. Moreover, the values of the test statistics calculated for counts of each of the structure categories observed in this sample are substantially larger than any of the other test statistics presented in the table. This suggests that the sample filter prepared from Sample 91 may not have been uniform so that there may be some question as to the relationship between the structure counts observed and the asbestos concentrations that may exist in the original sample. Nevertheless, results from this sample are included in the evaluation of the impact of asbestos discussed in later sections of this report. Moreover, the impact of any potential problems associated with the preparation and analysis of Sample 91 do not adversely affect the evaluation presented in the later sections of this report because asbestos concentrations observed in Sample 91 are not extreme relative to the other samples analyzed.

4.1.3 Duplicates

Two pairs of duplicate splits (both of ACM samples) were also prepared and analyzed as described in the Modified Elutriator Method to evaluate reproducibility[14]. This was accomplished by testing for consistency in the structure counts observed on each split of each duplicate for each of three structure size categories (total protocol structures, 7402 structures, and total asbestos structures). Results are presented in Table 4.

The test statistic for comparing duplicates is determined as:

$$(a - b)/(a + b)^{0.5} \qquad (4.2)$$

where a and b are the counts of the number of structures observed (in a particular size category) during the analysis of each split of the duplicate pair, respectively.

The critical value for this test statistic is based on the fact that a Poisson distribution can be approximated as a normal distribution with a mean of zero and a standard deviation of 1. The critical value for such a distribution (at the 0.05 level of significance, two-tailed) is 1.96, which is the corresponding z-value for a normal distribution (Box et al. 1978). Note that this procedure is equivalent to comparing the results of paired measurements using a chi-square analysis with the critical value derived from a chi-square distribution with one degree of freedom (see, for example, Box et al. 1978 or the discussion in Section 4.1.2 above). The only difference is that the equation used for calculating the test statistic and the critical value are the square roots of those used in a typical chi-square test.

In Table 4, the first column indicates which samples are paired and the second column indicates the sample number. The next three columns indicate the number of structures observed in each sample, respectively, for each of three structure categories: total protocol structures, 7402 structures, and total asbestos structures. The test statistics (calculated as described in Equation 4.2) derived from the counts observed over each pair of duplicate samples for each respective structure category are presented in the next three columns. The last three columns of the table indicate whether the counts on each sample of a duplicate pair can be considered to be statistically similar (consistent) for each of the respective structure size categories.

As can be seen in Table 4, counts of each structure category observed on the first set of duplicate samples are entirely consistent. The second set of paired duplicates show only a single structure between them (a protocol structure, which is also counted among total asbestos structures). Nevertheless, as indicated in the table, the results from this second set of duplicate samples are also entirely consistent. Note that the test statistic is "undefined" for 7402 structures because no structures were observed on either

[14] Note that the two samples were labeled in a manner so that the laboratory could not tell that they were duplicates. Thus these samples were analyzed "blind."

sample, so that Equation 4.2 reduces to the quotient of zero over zero, which is undefined. Nevertheless, observation of zero structures on both samples represents identical measurements, which means perfect agreement.

Given the above, which is consistent with general observations concerning analyses of homogenized splits using the Modified Elutriator Method, the analytical results obtained in this study can be considered to be reproducible.

4.1.4 Evaluating consistency across soil and ACM samples

Just as chi-square analyses were used to evaluate consistency across grid specimens prepared from a single sample filter, chi-square analyses were also used to evaluate consistency across sets of related samples. Results are presented in Table 5.

In Table 5, the specific sets of samples evaluated are identified in Column 1. The second column indicates the sample type (soil or ACM). The third, fourth, and fifth columns indicate, respectively, the number of samples within each sample set, the number of degrees of freedom for the chi-square analysis (one less than the number of samples), and the corresponding critical value for the test (selected for a 5% level of significance).

The sixth, seventh, and eighth columns of Table 5 indicate the value of the test statistic calculated, respectively, for three size categories of structures (protocol structures, 7402 structures, and total asbestos structures) for each sample set evaluated[15]. The last three columns of Table 5 indicate whether asbestos concentrations observed among the samples of each particular set can be considered consistent for each of the three size categories of structures, respectively.

Based on the results presented in Table 5, soil concentrations observed among the 10 composite soil samples can be considered to be mutually consistent and appear to represent general concentrations in soils across the site, except in areas where hot spots may be present[16]. Results from the composite samples are clearly not consistent with asbestos concentrations observed in soils that are associated with hot spots. Asbestos concentrations in soils associated with hot spots are significantly higher than concentrations observed in general site soils.

Concentrations of asbestos observed in the ACM components of the samples are not mutually consistent. This is true whether the sample set is restricted to ACM collected from composite samples or whether ACM samples from hot spots are included. Although not shown in the table, it was also found that asbestos concentrations in ACM collected exclusively at hot spot locations are significantly different from one another. Not surprisingly, this suggests disparate character and conditions for ACM collected

---

[15] The number of structures observed in each sample from each set is presented in Table 1.

[16] As used here, the term “hot spot” means areas of the site where high concentrations of ACM or particularly weathered ACM are present (as defined in Section 2).

over different portions of the site. This is consistent with field observations indicating multiple types of ACM are present and that the relative degree of weathering differs from location to location.

4.1.5 Conclusions concerning data quality

Based on the results presented above, asbestos concentrations determined as described in the Modified Elutriator Method in soil and ACM samples collected from the site can be considered reliable and reproducible. It is also apparent that asbestos concentrations in site soils in areas remote from high concentrations of ACM are generally low and consistent. In contrast, asbestos concentrations in soils associated with hot spot areas may contain significantly higher concentrations of asbestos. Moreover, asbestos concentrations in ACM appear to vary substantially from one location to the next at the site. This is not surprising as both the types of ACM (roofing material, transite siding, etc.) and the relative degree of weathering of the ACM vary from one location to the next.

4.2 Relating Asbestos Concentrations and ACM Mass in Soil

Given that the asbestos observed in the soil components of samples from the North Ridge Estates site is expected to have derived from the ACM in each sample[17], the relationship between asbestos concentrations in soil components and the corresponding ACM components of particular samples is further evaluated. The relevant data are summarized in Table 6 and have been sorted in ascending order by the mass fraction of the ACM observed in each sample.

In Table 6 (as in Table 1), Columns 1 through 3 indicate the soil component sample number, the ACM component sample number, and the location from which such samples were collected. Column 4 indicates the mass fraction of ACM observed in each particular sample. As previously indicated, the data in this table have been sorted so that sample results are presented as a function of increasing values in this column.

The fifth through seventh columns of Table 6 indicate, respectively, the concentrations of total protocol structures, long protocol structures, and 7402 structures observed in the soil component of each sample. Columns 8 through 10 indicate the concentrations of the same structures observed among the ACM component of each sample.

Columns 11 through 13 of Table 6 indicate the estimated concentration of the various asbestos structures (i.e. total protocol structures, long protocol structures, and 7402 structures) that would be expected if such structures were derived solely from what was observed in the ACM fraction of the sample. These would be the concentrations of asbestos in soils that would occur if the embedded ACM completely degraded to leave only free asbestos structures (and that the soils were initially asbestos-free). Such

---

[17] As discussed at the end of this section (see discussion of Figure 1), any asbestos observed in composite samples from this site may also have derived from ACM that was previously removed from the sampled material during a historical surficial removal of ACM (Wroble, private communication).

concentration estimates are determined by multiplying the concentrations observed in the ACM component by the mass fraction of ACM in the sample.

Note, as described in the interpretation section of this report, estimates of the concentration in a soil sample that is attributable to the embedded ACM can be used to evaluate the effect of the presence of such ACM associated with exposure pathways that involve the disturbance and/or handling of soils. In contrast, it is the concentration of asbestos in the ACM itself (as presented in Columns 8 through 10 of Table 6) that is used to evaluate effects associated with exposure pathways involving handling of pure and isolated ACM.

The last three columns of Table 6 indicate, respectively, the estimated total concentrations of the various asbestos structures in each sample. This is derived by summing the contribution of asbestos in soils estimated for the ACM component (Columns 8 through 10) with the contribution observed in the soil component itself (Columns 5 through 7). As indicated below, such total concentrations can be used to evaluate the overall impact associated with handling soils containing ACM via each of the various exposure pathways of interest. In contrast, the concentrations observed in soil components of samples from which ACM has been removed (as reported in Columns 5 through 7) can be used to assess hazards associated with the soil component itself.

To further clarify, one might think of the concentrations of asbestos in the soil component (Columns 5 to 7 of Table 6) as the concentrations of asbestos released from ACM due to the degree of disturbance and weathering that has already occurred to date. Then, the additional asbestos that may be added in the future (should the rest of the ACM completely degrade) would be equal to the concentrations determined in the ACM components of the sample (Columns 11 to 13 of Table 6). Additionally, the total concentrations of asbestos that may occur in the soil (which includes what has already been released from ACM and what may be released in the future) are presented in Columns 14 to 16 of the table.

It is also apparent in Table 6 that the concentrations of asbestos observed in the soil component of a sample generally (though certainly not monotonically) increase with increasing mass fraction of ACM in the sample. The single exception to this general trend is the sample from Hot Spot HS-7, where asbestos concentrations in the soil component are the highest observed in any sample despite the sample containing only 2% ACM. With this single sample omitted, asbestos concentrations in soil relate linearly with the mass fraction of ACM and the correlation between these two parameters for the seventeen remaining samples is depicted in Figure 1.

In Figure 1, the mass fraction of ACM in a sample is plotted on the X-axis and the concentration of asbestos in the soil component of the sample is plotted on the Y-axis. The slope of the best-fit trend line is 6×10^7. The correlation coefficient (r^2) is 0.302 ($r=0.55$). Such a correlation is significant. The critical value for rho (which is the test statistic for r) at the 0.05 level of significance and a sample size of 17 is 0.41 (Lowry 2004). Thus, the probability that such a correlation occurs by chance is less than 5%.

The single “outlier” sample (HS-7) to the above-described correlation was collected from a hillside in an area where water is likely to pool. The material from this area is highly weathered (much more highly weathered than material encountered anywhere else on site). The field crew reported that even the fine portion of the soil component appeared to contain many small pieces of ACM, which (due to the condition of the material) was virtually impossible to separate from the soil (Appendix A). Given such observations, it is not surprising that the soil component of this sample exhibits anomalously high asbestos concentrations relative to the mass of ACM observed in the sample, at least in comparison to the ratio of free asbestos to ACM observed in other samples. Relatively more of the ACM has already weathered at this location.

It should also be noted that some of the areas from which samples were collected have been historically subjected to ACM cleanup (see map in Appendix C of the Administrative Order of Consent for Removal Action and Streamlined Risk Assessment, May 20, 2003). Therefore, the original quantity of ACM in these samples may be underestimated. This would have two effects on the relationship depicted in Figure 1. First, it could potentially make the slope shallower so that more ACM would be required to be present before concentrations of asbestos in the soil component would pose a problem. This is because the samples in which little or no ACM was observed, which are primarily soil composite samples, may have been historically cleaned. In contrast, the high end samples in the figure are “hot spot” samples, which may not have been cleaned in recent years. Thus, if we could correct for this problem, the low end of the line would be raised relative to the high end.

The second effect that historical cleaning may have on the relationship depicted in Figure 1 would be to increase the variability of the observed values around the idealized relationship. Thus, if we had been able to sample “undisturbed” material (i.e. where cleanup had never been conducted), the correlation coefficient for the relationship might be higher than that currently observed. Nevertheless, as indicated above, the relationship that is observed is still statistically significant.

Importantly, although described here to support the general understanding that all of the asbestos observed at this site derives from ACM (i.e. from asbestos-containing construction debris), the correlation depicted in Figure 1 is not further applied to support the following risk assessment.

5. INTERPRETATION

A relatively simple bounding analysis was conducted and is reported in this section to provide an expeditious indication of risk. A bounding analysis is an analysis in which biased assumptions are incorporated to assure with high confidence that the results from the analysis are either greater or less then actual conditions, so that certain types of conclusions of interest (but not all conclusions) can be supported.

In this case, an extremely conservative, worst-case analysis of risk was conducted so that we can have high confidence that any actual risks would be less than what is estimated here. Thus, given the types of analysis conducted, conclusions indicating the lack of an unacceptable risk are valid because any actual risks will be even lower. In contrast, it is ***not*** valid to conclude from such a conservative, worst-case analysis that site risks are unacceptable (even if results from this analysis suggest that this may be the case). Rather, if estimated risks appear unacceptable from this type of analysis, the correct conclusion is that a more sophisticated and realistic (although still health-protective) analysis needs to be completed to assess whether actual risks are indeed unacceptable. Under such circumstances, more sophisticated modeling, perhaps coupled with a Monte Carlo type evaluation, would be required before concluding that site risks are indeed unacceptable.

A discussion of sources of uncertainties and the validity of conclusions is also presented in this report, following presentation of the bounding analysis conducted to estimate risk.

5.1 Linking bulk-phase measurements to risk

To interpret measurements of asbestos in soils and ACM (as presented in the last section), as previously indicated, it is necessary to establish the relationship between the asbestos concentrations observed in these bulk phases and concentrations that will occur in air when such soil (or ACM) is disturbed by natural or anthropogenic forces. This is because asbestos is a hazard when inhaled (see, for example, Berman and Crump 2001).

In fact, the Modified Elutriator Method (Berman and Kolk 2000)[18], which was the method employed to perform the analyses presented in this report, was designed specifically to facilitate prediction of airborne asbestos exposures based on bulk measurements (see, for example, Berman 1990). Briefly, the Modified Elutriator Method incorporates a procedure for isolating and concentrating asbestos structures as part of the respirable dust fraction of a sample and analytical measurements are reported as the number of asbestos structures per mass of respirable dust in the sample. These are precisely the dimensions required to combine such measurements with published dust emission and dispersion models to convert them to asbestos emission and dispersion models. Thus, because published dust emission and dispersion models can be used to address many of the exposure pathways of interest in this study (as described below), these can be combined with measurements from the Modified Elutriator Method to predict airborne exposures and assess the attendant risks.

In a previously published study (Berman 2000), this approach was applied to serpentine-surfaced (chrysotile containing) roads and the resulting predictions were compared against airborne asbestos concentrations that were actually measured

---

[18] The Modified Elutriator Method is a refined version of the Superfund Method (Berman and Kolk 1997) that incorporates modifications to improve performance and reduce cost.

downwind of the roads. Results from this study demonstrate that the indicated procedures yield predictions of airborne asbestos concentrations that are reasonably accurate. Moreover, the models used to develop the predictions do not require the use of any adjustable parameters. Thus, no calibration is required.

Importantly, there is nothing unique about the relationship between airborne dust concentrations predicted by the roadway model and the asbestos exposure concentrations estimated by multiplying such dust concentrations by the asbestos concentrations measured in the source material (i.e. the roadway surface) using the Modified Elutriator Method. Thus, dust concentrations estimated using any reliable emission and dispersion model can be multiplied by asbestos concentrations (measured in source material using the Modified Elutriator Method) to predict airborne asbestos concentrations in the same fashion. Therefore, this approach can be applied generally to any exposure pathway of interest provided that an appropriately matched dust emission and dispersion model has been published or can be adapted from available models addressing similar pathways.

As indicated above, although individual measurements derived using the Modified Elutriator Method (Berman and Kolk 2000) are not inherently conservative (rather they appear to be accurate)[19], conservative estimates of concentrations can be obtained from sets of such measurements using approaches that are common for deriving conservative estimates for other hazardous materials. For example, if statistical upper-bound estimates of the measured concentrations or the maximum of measured concentrations are selected for use, these constitute conservative, bounding estimates of concentration. Moreover, use of conservative (rather than best) estimate values as input parameters for the emission and dispersion models that are combined with such measurements also converts what may otherwise by unbiased analyses into conservative, bounding analyses as in the case presented below.

5.2 Selecting exposure pathways.

To assess exposure in association with release of asbestos from local soils, exposure pathways associated with common residential activities and with potential future construction were both evaluated. The exposure pathways considered in this report in association with residential activities that could disturb local soils are:

- inhalation of dust generated while children play or adults garden in soil;
- inhalation of dust generated during walking, running, bicycling, or riding an all terrain vehicle (ATV) over unpaved surfaces at the site; and
- inhalation of dust generated during rototilling.

---

19 As with analytical methods in general, the Modified Elutriator Method is designed to provide an unbiased estimate of concentration.

The special exposure pathway associated with a child (or adult) physically handling and abrading a piece of ACM was also evaluated.

Except potentially for pathways involving exposure to dust generated during local construction (which are discussed below), the exposure pathways analyzed in this report include the exposure pathways that potentially generate the greatest contributions to overall, outdoor, residential exposure, based on best professional judgment. Wind entrainment, for example, typically results in exposure concentrations that are substantially smaller than those associated with the exposure pathways evaluated here. Moreover, exposure due to dust generated from wind entrainment will only occur on days when substantial wind velocities (greater than approximately 20 mph) occur (Cowherd et al. 1985). Thus, contributions to overall exposure from wind entrainment are typically much smaller than those estimated here and are not addressed further.

Exposures potentially experienced by workers who may disturb soil during potential future excavation and construction in the area were also evaluated. Because residents may also experience exposure during future construction projects, such exposures are also evaluated, although (as expected) they are substantially smaller than those estimated for the workers themselves.

5.3 Assessing Exposure.

Exposures potentially associated with each of the pathways identified above were estimated as follows. First, published dust emission models were selected to estimate dust emissions attributable to each of the pathways evaluated. Second, the emission models were combined with simple dispersion models (box models) to derive instantaneous dust exposure concentrations attributable to each pathway. Third, the instantaneous dust concentrations were combined with conservative estimates of the duration and frequency of exposure associated with each pathway to derive conservative estimates of long-term average dust exposure concentrations. Finally, long-term average dust exposure concentrations were multiplied by the ratios of asbestos structures to respirable dust measured in bulk source material (and reported in Section 3) to convert dust exposure concentrations to asbestos exposure concentrations.

In the following subsections of this section:

- the models adapted and applied to estimate dust exposure are described;
- the data and assumptions employed to develop input values for the dust emission and dispersion models are summarized;
- the dust exposure concentrations estimated from dust emission and dispersion modeling are presented; and

- the asbestos exposure concentrations (derived by combining dust exposure concentrations with asbestos concentrations in bulk materials) are provided.

5.3.1 Emission and dispersion models

When an emission model directly applicable to a particular exposure pathway of interest was not available, models representing modes of disturbance with similar dynamics were adapted for that pathway of interest. Although such adaptations have not been validated, they were based on professional judgment and are believed to be reasonably conservative. Also, in some cases, the adaptations introduced for modeling some of the pathways of interest require use of the models outside the range of parameters over which such models have been formally evaluated and validated. This generally increases the overall uncertainty of the modeled results. However, most of the adaptations introduced in this report should tend to cause the models to overestimate (rather than underestimate) exposure, as described below.

Detailed considerations for each model are described in the following subsections of this chapter.

Playing and Gardening

To estimate exposure (and the attendant risk) for children playing and adults gardening, the U.S. EPA model for soil handling (U.S. EPA 2002) was adapted. A description of the model and details of the manner in which it was adapted for use in this report are provided in Table 7.

In Table 7, the original equation representing the U.S.EPA soil handling model is presented on the top left with one modification. All of the input parameters and output variables are also defined. For the one modification, a term, R_M, (which represents the rate of mass handling) was added simply to convert the output emission rate of the model from one of mass emitted/mass handled to one of mass emitted/time. As indicated under the heading, “Modifications,” only one additional modification was required to convert this model from a dust emission to an asbestos emission model that can be applied to gardening and child’s play. This was to incorporate the parameter, $R_{a/d}$, as a multiplicative factor. $R_{a/d}$ is simply the ratio of asbestos to dust determined in bulk source material using the Modified Elutriator Method (Berman and Kolk 2000).

The emission model is then combined with a simple box (dispersion) model in the manner described under the heading “Exposure Point Concentrations Estimated at Receptor” to convert the output from a rate (str/sec) to a concentration (str/cm^3). The box model has units of sec/m^3 and is intended to reflect (the reciprocal of) the volume of air that moves through the space between the location where source material is being disturbed and the breathing zone of the receptor. This volume is calculated simply as the product of the cross-wind width (W_{cp}) of the box, the cross-wind height (h) of the box, and the speed (U) of the wind entering the box. Wind can represent either the speed of local wind in the area or, for moving sources, the speed that the source moves within the surrounding air. This is the air into which the emitted asbestos (or dust) is diluted prior to being inhaled. Note that a conversion factor is also incorporated into the combined equation so that the resulting concentrations are reported in units of str/cm^3 (or g/cm^3 when dust exposure concentrations are being discussed).

It makes no difference whether the term $R_{a/d}$ is added to the rate equation first or whether the rate equation is multiplied by the box model to convert it to an exposure model first. In the former case, asbestos emission rates are estimated and input into the dispersion model to estimate exposure point concentrations for asbestos. In the latter case, dust emissions are estimated and input into the dispersion model to estimate exposure point concentrations for dust, which are then converted to asbestos concentrations by multiplying by $R_{a/d}$. In either case, results are equivalent.

In the discussion to follow, the latter of the above-described approaches is adopted so that exposure point concentrations for dust are first estimated and these are then converted to asbestos concentrations as the last step of this exposure assessment. Values adopted for the input parameters to the model for gardening and child's play (and all other models applied in this assessment) are described in detail in the section following this discussion of the models.

Walking, Running, Bicycling, ATV riding on Unpaved Surfaces

To estimate exposure (and the attendant risk) for individuals walking, running, bicycling, or ATV riding over unpaved surfaces of the site, the original Copeland model (U.S.EPA 1985), which was developed to describe emissions from off-road vehicle traffic, was adapted to the conditions associated with these additional pathways. A description of the model and details of the manner in which it was adapted for use in this report are provided in Table 8.

Importantly, the model currently adapted to estimate exposure associated with walking, running, bicycling, or ATV riding actually represents exposure concentrations likely to be experienced by an individual following closely behind a leader while conducting the indicated activity. Therefore, such a model is expected to substantially overestimate exposure to a single individual who might be conducting the indicated activity alone. This is because an individual walking, running, or bicycling would be constantly moving ahead of the dust cloud that they generate so that they spend little to no time inhaling dust from their own plume. Especially given that it is unlikely that any particular individual would be constantly following immediately behind other runners, walkers, or bicyclists for even a substantial fraction of the time that they spend pursuing such activities, the exposure estimates provided for participants in such activities should be considered to be extremely conservative (upper-bound) estimates.

A more sophisticated (and time-consuming) modeling effort would be needed to reasonably evaluate exposure to individual walkers, runners, bicyclists, or ATV riders than the one that was completed for the estimates provided in this report. Such an approach would not be required, however, unless risks estimated using the current, bounding approach are found to be unacceptable. As previously indicated, while it may be valid to support conclusions concerning lack of unacceptable risks using results from a conservative, bounding evaluation, conclusions concerning existence of an unacceptable risk would not be valid. Rather, if such a problem would be suggested, the more sophisticated analysis would need to be conducted before valid conclusions could be drawn.

In Table 8, the original equation representing the Copeland model is presented on the top left with all of the associated input parameters and output variables defined. The modifications required to convert the model to metric units is then indicated in the next section of the table.

On the second page of the table, as indicated under the heading "modifications," this model was modified to address asbestos in a manner entirely analogous to that described for the soil handling model above: the multiplicative factor, "$R_{a/d}$" was incorporated into the model. As previously indicated, this parameter simply represents the ratio of asbestos to dust determined in the bulk source material using the Modified Elutriator Method.

Also as indicated under "modifications," the Copeland model was modified by incorporating parameters representing the fraction of time spent on bare vs. vegetated (or paved) ground (T_f) and an emission reduction factor (V_f) to account for the reduction in dust (or asbestos) emissions that would occur from the protection afforded by ground cover.

In the lower half of Table 8 (under the heading, "Exposure Point Concentrations Estimated at Receptor"), it is shown how the emission model is then combined with a simple box (dispersion) model to convert the output from an emission rate to an exposure point concentration. This is accomplished in a manner identical to that previously described for the soil handling model. Moreover, as with the soil handling model, it makes no difference with this model whether the modifications required to convert the model from one for dust to one for asbestos are applied before or after converting the rate model to a concentration model.

It must also be emphasized that the principal modifications applied to the Copeland model to adapt it for estimating emissions and exposure concentrations associated with walking, running, and bicycling involve modifications to the values for particular input parameters. Specifically, the value for the number of wheels ("w" in the equation) is adjusted to account both for the actual number of wheels (or feet) and for the relative size of the footprint (i.e. the size of the area in direct contact with the ground) of each wheel (or foot) associated with each activity. While the latter is a novel adaptation, it appears justifiable, given the dynamics of dust generation associated with these activities and vehicle traffic on unpaved roads in general. That is, the rate of dust generation relates both to the pressure applied (which is addressed by adjusting the "vehicle" weight parameter) when the wheel or foot is in contact with the ground and to the surface area over which the pressure is applied. Interestingly, due to the relative pressures to which various vehicle tires are typically inflated, this "footprint" consideration appears to have been taken into account by default in the original model, at least over the range of vehicles to which it is commonly applied (see Appendix C). For similar reasons (i.e. the similarity of tire pressures commonly employed in ATV tires and automobile tires), such modifications are not required when applying the model to ATV riding.

Although the dynamics in which a wheel is in contact with a surface and a foot is in contact with a surface differ somewhat, such differences seem to be reasonably minor for this adaptation. For example, consider that (for moving vehicles) any particular portion of a tire is placed rapidly on the ground, remains on the ground for a finite period, and is then lifted. This mimics the actions of a foot during walking or running, although (particularly for running) the relative force with which a foot hits the ground (after free-falling for a short distance) may be somewhat greater relative to the weight of the person (or vehicle) than addressed in the model. Still, this effect should introduce only a modest error because the distance of free fall is so small.

In fact, the Copeland Model as adapted for walking or running is likely conservative for two reasons. First, consider that tire contact is continuous while foot contact is intermittent (so that relatively large fractions of the roadway or footpath go untouched between footsteps). Second, consider that tire treads tend to be relatively deep and are designed to be continuous (to channel rain). This also provides an efficient channel for escape of dust while the ground is pressed whereas the bottom of shoes and sneakers have relatively shallower and discontinuous "treads" that are not as well suited for channeling dust.

The first of the above-listed factors alone suggests that dust emissions during walking may only be about one third of that estimated using the adapted model because a normal stride is about three times the length of a typical foot and its corresponding footprint. During running, the fraction of a stride over which a foot is in direct contact with the ground is even smaller.

Given the considerations indicated above, it seems that despite the Copeland model being adapted to scenarios in which the values for input parameters are outside the ranges over which the model has been formally validated, if anything, the adapted model should overestimate emissions and exposure, rather than underestimate them for the scenarios addressed here. The specific parameter values employed for modeling walking, running, bicycling, and ATV riding using this model are described in the next section (Section 5.3.2).

Rototilling

To estimate emissions from rototilling, a model designed to estimate emissions from agricultural tilling (Cowherd et al. 1974) was adapted. A description of this model and the adaptations incorporated for this analysis are described in Table 9.

As can be seen in Table 9, two modifications were incorporated into the Cowherd et al. tilling model to adapt it for this document. These are: (1) incorporation of the particle size factor, k, to convert the total suspended particulate matter output of the model to PM_{10} and (2) incorporation of a conversion factor, Q_3, to convert the output of the emission model from lbs_{PM10}/acre to g_{PM10}/sec.

The manner in which Q_3 was derived is also indicated in Table 9. It requires assumptions concerning the width of the path tilled by a typical rototiller (assumed to be 1ft) and the speed with which rototilling is performed (assumed to be one half the speed of walking). With these two assumptions, the time required to till an acre is determined along with its inverse (the number of acres tilled per second). Q_3 is then determined simply as the product of the number of g/lb (454) and the estimated rate for rototilling an acre.

It should also be noted that this model contains no parameter for addressing the effects of moisture content. Although it is tempting to multiply this model by the moisture content term that has been developed for several other emission models $(M/0.2)^{0.3}$, the appropriateness of this term (particularly the appropriateness of using a reference moisture content of 0.2%) for this model is not known. Therefore, to be conservative, a moisture content term was not added to the model. Consequently, consideration of the effects of moisture content on emissions from rototilling will be addressed qualitatively.

As indicated under the heading "modifications," this model was modified to address asbestos in a manner entirely analogous to that described for the soil handling and Copeland models above: the multiplicative factor, "$R_{a/d}$" was incorporated into the model. As previously indicated, this parameter simply represents the ratio of asbestos to dust determined in the bulk source material using the Modified Elutriator Method.

In the lower half of Table 9 (under the heading, "Exposure Point Concentrations Estimated at Receptor"), it is shown how the emission model is then combined with a simple box (dispersion) model to convert the output from an emission rate to an exposure point concentration. This is accomplished in a manner identical to that previously described for the soil handling and Copeland models. Moreover, as with these other models, it makes no difference with this model whether the modifications required to convert the model from one for dust to one for asbestos are applied before or after converting the rate model to a concentration model.

Handling or Playing with ACM

To evaluate exposure and the attendant risk associated with the handling of ACM, the "back-of-the-envelope" model originally reported in Appendix A of the Human Health Risk Assessment Work Plan for this site (Berman 2003c) has been modified to facilitate incorporation of the measured asbestos concentrations that are now available. The model was also adapted to parallel the format adopted for the other emission and dispersion models discussed in this section. The "model," as newly adapted, is described in detail in Table 10. This model was designed to provide a conservative estimate of exposures associated with the handling of ACM and will be used for this purpose unless a more sophisticated approach needs to be developed. Because the current model is subject to greater uncertainty than other models employed in this study, if estimated risks are even close to target criteria, use of a more sophisticated approach would be recommended.

In Table 10, a summary of the scenario modeled is presented in the shaded insert on the upper left. As indicated, the scenario involves a child picking up a conveniently sized piece of ACM and using it as chalk to write on a paved surface. During such activity: the ACM will tend to degrade through abrasion, a portion of the abraded material will become airborne, and a fraction of the airborne material will be respirable (including respirable asbestos structures). As it is being produced, the respirable material will be diluted in air that moves through the space between the point that the abrasion is occurring and the nose of the child. Thus, the exposure concentration experienced by the child will be a function both of the rate of abrasion and the rate of airflow into the “box” encompassing the source activity and the child’s nose. In turn, airflow into the box is a function both of local wind conditions and of turbulence induced by movement associated with the handling of the ACM.

The equation describing the emission model for handling ACM is presented on the top in the middle of Table 10. This initial equation indicates the relationship between a predicted dust emission rate for ACM handling and (1) the mass of ACM handled; (2) the fraction of ACM abraded during handling; (3) the fraction of abraded material that is sufficiently degraded to become respirable; and (4) the length of time during which the ACM is handled.

Estimated values for the unique variables of this model are presented in the next lower section of Table 10. As can be seen, a piece of ACM that is conveniently sized for handling is evaluated and the mass is estimated at 380 g. Assumptions concerning the fraction of this mass that is crumbled during handling and the fraction of the material crumbled that degrades sufficiently to become respirable are also presented. As indicated, these are educated estimates that nevertheless seem reasonable. Unless additional data become available from U.S.EPA, it is also recommended that a bench-scale laboratory simulation be conducted to provide data useful for better characterizing the fraction of handled ACM that becomes respirable when crumbled.

As further indicated under the heading, “modifications” in Table 10, this model is modified to address asbestos in a manner entirely analogous to that described for the soil handling and Copeland models above: the multiplicative factor, “$R_{a/d}$” was incorporated into the model. As previously indicated, this parameter simply represents the ratio of asbestos to dust determined in the bulk source material using the Modified Elutriator Method.

In the lower half of Table 10 (under the heading, “Exposure Point Concentrations Estimated at Receptor”), it is shown how the emission model for ACM handling is combined with a simple box (dispersion) model to convert the output from an emission rate to an exposure point concentration. This is accomplished in a manner identical to that previously described for the soil handling and Copeland models. Moreover, as with these other models, it makes no difference with this model whether the modifications required to convert the model from one for dust to one for asbestos are applied before or after converting the rate model to a concentration model.

Worker Exposure during Excavation and Construction

Operations that potentially generate the greatest quantities of dust from local soils and fill during construction activities are:

- bulldozer excavation;
- loading and dumping;
- grading; and
- transport over unpaved surfaces.

Each of these activities was modeled to support this evaluation using published dust-emission models that are specific to each activity. The model for loading and dumping is the same model that was adapted for gardening and children playing in dirt and has been previously discussed (Table 7). The models for bulldozer excavation and grading are presented in Table 11. The model for vehicular transport over unpaved surfaces is presented in Table 12. In Table 11, the original equations representing the U.S.EPA models for bulldozer excavation and grading are presented on the top left with all of the input parameters and output variables defined.

As indicated under the heading, “Modifications,” the only modification made to these models is that the parameter, $R_{a/d}$, is incorporated as a multiplicative factor to convert the output from dust emissions (g_{PM10}/sec) to asbestos emissions (str/sec). $R_{a/d}$ is simply the ratio of asbestos to dust determined in bulk source material using the Modified Elutriator Method (Berman and Kolk 2000).

These emission models are then combined with a simple box (dispersion) model in the manner described under the heading “Exposure Point Concentrations Estimated at Receptor” to convert the output from a rate (str/sec) to a concentration (str/cm^3). The box model has units of sec/m^3 and is intended to reflect (the reciprocal of) the volume of air that moves through the space between the location where source material is being disturbed and the breathing zone of the receptor. This volume is calculated simply as the product of the cross-wind width (W_{cp}) of the box, the cross-wind height (h) of the box, and the speed (U) of the wind entering the box. Wind can represent either the speed of local wind in the area or, for moving sources, the speed that the source moves within the surrounding air. This is the air into which the emitted asbestos (or dust) is diluted prior to being inhaled. Note that a conversion factor is also incorporated into the combined equation so that the resulting concentrations are reported in units of str/cm^3.

The scenario modeled here is one in which individual workers spend a majority of the project working adjacent to the heavy equipment required to complete excavation and construction (i.e. bulldozers or graders). Although unlikely, this is possible for certain kinds of construction activities. Therefore, dispersion was modeled as described above using a localized box model. This is in fact a much more conservative approach than that recommended in the latest U.S.EPA guidance (2002) in which it is assumed that workers spend their time averaged over the construction area as a whole and, independently, the heavy equipment is also moved around the site. The result is that, in the U.S.EPA approach, emissions are assumed to be averaged over a much larger box covering the entire construction site. As described below, in contrast, this latter approach is used here only to model emissions and dispersion from transport (as recommended in the U.S.EPA guidance).

The U.S.EPA model for emissions from construction-related transport on unpaved surfaces (Table 12) is handled somewhat differently than the other models. This is because, unlike the other dust-generating activities evaluated in this document, it is unlikely that personnel (other than the driver – and he moves out ahead of the plume) will remain constantly in close proximity to vehicles that might be hauling construction-related material to or from the site. Thus, exposure associated with dust generation from such vehicle transport must be averaged over a larger area than the kinds of small-scale box models that are employed for the other exposure pathways evaluated in this document.

Given the above, the approach adopted to evaluate dispersion and exposure associated with construction-related vehicle transport is that recommended in the U.S.EPA soil screening guide (2002). By this approach, emissions from vehicular transport are assumed to be generated on average from a line source bisecting the entire site (which represents an average haul road) and that emissions disperse into an area equal in size to the entire construction site.

The equation used to model dispersion in the manner described above, along with definitions for the associated parameters of the equation, are presented in the lower half of Table 12, under the heading, “exposure point concentrations estimated at receptor.” The dispersion factor, “Q/C” is derived based on another equation provided in U.S.EPA (2002, Appendix D), which is a function of the size of the construction site. This equation (along with definitions for the input parameters) is also presented in Table 12. The values adopted for the various parameters of each of these models to estimate exposure at the North Ridge Estates Site are presented in the section that follows (Section 5.3.2).

As indicated at the bottom of Table 12, the manner in which the equations used to estimate exposure associated with construction-related transport on unpaved surfaces in this document are converted to asbestos models from dust models is identical to that described for every other model employed in this study. Simply, the equations are modified by incorporating the multiplicative factor, $R_{a/d}$, which is simply the ratio of asbestos to dust determined in bulk source material using the Modified Elutriator Method (Berman and Kolk 2000).

5.3.2 Values for input parameters to the emission and dispersion models

Exposure was estimated for each of the exposure pathways of interest in this study by inputting appropriate values for the parameters of the corresponding models described in the last section. A summary of the values for input parameters employed in this study is provided in Table 13.

In Table 13, the first two columns present the name and the mathematical symbol for each input variable (parameter), respectively. The next 11 columns of the table indicate, respectively, the input values selected for walking, running, bicycling, ATV riding, rototilling, child-play and gardening, handling ACM, bulldozer excavation, loading or dumping, grading, and construction-related transport. Note that blanks in the cells of this table indicate that a particular input parameter is not relevant to a particular model. The last two columns of Table 13 indicate, respectively, the units for each input variable and a brief description of the source of the values selected. A more detailed discussion of the source and justification for the values selected for each input variable is provided below:

- **Particle size multiplier.** The value of 0.35 selected for this variable is the value recommended by EPA (see, for example, U.S.EPA 2000b) to adjust emission estimates so that they represent the respirable (PM_{10}) fraction of dust.

- **Moisture content.** For activities that are performed at the surface of the site (such as walking, running, bicycling, or ATV riding), the conservative (low) value of 0.2% that is recommended by U.S.EPA (see, for example, U.S.EPA 2002) has been assumed. For activities in which sub-surface soils are disturbed, a value of 2% is employed, which reflects that fact that subsurface soils are typically wetter than those immediately at the surface. Based on professional judgment, this value is expected to be conservative for subsurface soils. Moreover, this value is more conservative than the default values that the U.S.EPA (1985) recommends for handling of piles or other non-surficial materials and compares favorably to reported values for the moisture contents of storage piles and other non-surficial materials (U.S.EPA 1985). Should consideration of this specific parameter be deemed critical, it is also possible to measure moisture content directly from the site.

- **Number of wet-days per year.** The value of 90 selected for the number of wet days is a conservative, site-specific estimate obtained from a U.S.EPA published isopleth map of such values (U.S.EPA 2002, Page 5-13).

- **The Thornswaite PE index.** The value of 32 selected for this parameter is derived from a U.S.EPA published isopleth map of such values (U.S.EPA 1985).

- **Silt content.** To be conservative, the value of 38% selected for silt content was set equal to the maximum value observed among all of the measurements collected during the study of the site. A summary of measured silt content values is provided in Appendix D.

- **Gross vehicle speed.** For models in which vehicles (or humans) are moving, the speed of such movement was selected to be conservatively high. Thus, for walking, running, and bicycling conservative values of 4, 6, and 10 mph (6, 9.6, and 16 kph) were selected. Due to the durations and frequencies assumed for these activities (see Section 5.3.3), such activities must be considered long-distance activities, so that the speeds selected are extremely conservative. Regarding running, for example, expecting someone to maintain a 6 mph pace every day for two hours per day over 30 years is simply unrealistic. Thus, the number of days assumed for maintaining this speed was also reduced from 365 days/year to 250 days/year (see Section 5.3.3). Even so, this combination of speed and frequency for running remains extremely conservative. Vehicle speeds assumed for rototilling, ATV riding, and construction-related excavation, grading, and transport on unpaved roads are similarly conservative. For example, pushing a hand rototiller at a pace equivalent to a half the speed of a brisk walk (2 mph) is fast. Typically, one pushes a rototiller only very slowly and stops are frequent.

- **Asbestos concentration in dust.** As previously indicated (Section 5.3.1), this is the concentration of asbestos measured in soils and fill at the site using the Modified Elutriator Method and reported as the number of asbestos structures per gram of respirable dust (str/g_{PM10}). Asbestos concentration estimates adopted as inputs for specific models are discussed in Section 5.3.4.

- **Mass material handling rate.** The value of 0.125 Mg/hr that is assumed for children playing and adults gardening is based on the extremely conservative estimate that an individual working with small hand-tools can excavate 0.5 m^3 of material in an hour. For commercial construction, the value of 14 Mg/hr assumes that backhoe workers excavate a trench that is one meter deep, one meter wide, and 50 meters long in 8 hours (50 m^3/day), which is extremely conservative. To put this in perspective, consider that, if one built 20 new homes over the course of a year and excavated an acre of material to a depth of one meter for each home (a highly unlikely scenario), the rate of material handling would only be about 5 m^3/day ([20 homes x 63.6 m^3/home]/250 working days per year).

- **Wind Velocity.** For moving sources, clearly the minimum relevant wind speed is equal to the speed of the moving source. Thus, for bicycling and ATV riding speeds of 4.4, and 8.3 m/sec (10, and 18 mph), respectively, represent reasonable estimates. For walking, running, and rototilling, because these activities are much slower, the average wind speed for the area (3.0 m/s or 6.7 mph) was assumed. For construction activities, although sources are moving, nearby workers are stationary. Therefore, the mean wind velocity reported for Klamath Falls of 3.0 m/s (6.7 mph, Western Regional Climate Center 2004) is assumed. For residential activities (gardening, child's play, ACM handling) involving stationary sources, one half of the mean local wind velocity is assumed to account for the relatively small box within which dispersion occurs in association with these activities.

- **Gross vehicle weight.** The gross vehicle (personal) weight assumed for walkers or runners is 0.073 Mg (160 lbs, which is the EPA recommended value for adult males, U.S.EPA 1997). For bicyclists, 30 lbs was added for the weight of the bicycle. For ATV riding, the vehicle was assumed to weigh 1,000 lbs (including the rider). For construction-related transport, 20 Mg is assumed, which is the mass of a 20 ton truck.

- **Number of vehicle wheels.** The number of wheels (or feet) assumed for walkers, runners, bicyclists and ATV riders is listed in Table 13 and a detailed discussion of the derivation of these values is provided in Section 5.3.1**.**

- **Emission reduction factor.** An emission reduction factor of 0.01 is assumed in this study. This is a default value recommended for wind erosion (see U.S.EPA 2002). However, the degree to which the value of this factor is also appropriate for walking, running, or bicycling is unclear so that this may contribute somewhat to the overall uncertainty of the modeling effort. At the same time, walkers, runners, and bicyclists likely spend a fair fraction of their time on paved surfaces, where the emission reduction factor would be zero. Thus, use of this factor is unlikely to contribute to any underestimation in risk.

- **Fraction of time spent on bare ground.** Assuming that walkers, runners, bicyclists, and ATV riders spend approximately 50% of their time on vegetated or paved surfaces seems to be a reasonably conservative estimate, particularly for runners and bicyclists, who generally prefer smoother surfaces. Interestingly, 50% is the default value recommended for wind erosion pathways (U.S.EPA 2002), which suggests that one should assume that 50% of a site is covered either with vegetation or paving. Thus, since individuals who walk, run, or ride likely prefer the smoother surfaces, this estimate is likely conservative.

- **Width of the dispersion box.** The values selected for the width of the box into which emissions disperse are chosen to be reasonably conservative for each of the exposure pathways addressed, based on a complex set of considerations. These are described in Appendix E.

- **Height of the dispersion box.** For all exposure scenarios except gardening/children playing, handling of ACM, and ATV riding, the height of the box into which emissions disperse is selected to be 1.75 m, which is the approximate height of an adult. For gardening/children playing and handling of ACM, the height of the box is estimated at 0.5 m, which is the approximate distance between the hand and nose of a stooping adolescent. Given that this averaged over a 30-year period and that the adolescent will mature over that period, this last value is clearly conservative. The height of the mixing box for ATV riding is about twice the height of a seated adult (2 m). This was adopted to account for turbulent dispersion in the wake of the vehicle. Also, regarding ATV riding, the discussion in Section 5.5.1 should be considered. These values are also addressed further in Appendix E.

Note that all of the remaining parameter values are associated solely with construction-related transport:

- **The dispersion factor (Q/C**). This is described in detail by the U.S.EPA (2002, Appendix D) and is determined by the Equation presented on the lower left of Table 13. It is a function of three constants that are defined in U.S.EPA (2002) and the areal extent of the site over which construction is assumed to occur. In this study, construction is assumed to occur in the vicinity of the occupied houses, which covers an area of 153 acres (Berri, D. PBS, private communication 2004, based on measurements from a scale map).

- **Dispersion adjustment factor.** This too is defined in U.S.EPA (2002) and the default value of 0.182 is employed.

- **Road surface area.** This is the surface area of the unpaved haul road that is assumed to be constructed to facilitate transport to and from the construction area (U.S.EPA 2002). As described in EPA guidance, it is estimated as the length equal to the distance from the middle to the edge of the (153 acre) site (approximately 1.8 km, see Lroad below) and the width of a typical single lane road (15 ft or approximately 5 m). This is extremely conservative because there are already paved roads traversing the site so that transport over unpaved surfaces to any new construction site will be substantially less than that assumed.

- **Number of vehicle Km traveled**. This is estimated simply as the length of the haul road times the number of loads assumed (both indicated below).

- **Total area of project site.** As previously indicated, this is assumed to be the area over which houses currently exist at the site, which is an area of 153 acres (Berri, D. PBS private communication 2004, based on measurements from scale map).

- **Loads per project.** This was assumed simply to be two loads per day over a 1-year project.

- **Length of road.** This is the length of the haul road over which construction-related transport is assumed to occur. As described in guidance (U.S.EPA 2002), it was estimated simply as the distance between the center and the edge of the site. Thus, 1.1 km is derived as 1.414 x 208 ft/side of acre x $153^{0.5}$ acres (side of square) x 3E-4 km/ft. Note that the term, 1.414, is simply the square root of 2, which is the length of the diagonal of a square relative to the side of a square. Thus, the equation simply provides a determination of the distance along the diagonal from the center to the edge of a square-shaped site that is the same size of the North Ridge Estates site. This is the longest possible distance between the center and closest edge of any shaped site of the size indicated.

- **Active project time.** For the standard construction project evaluated in this document, which is assumed to last a year, this is estimated simply as the number of seconds in an occupational year (60 x 60 x 8 x 250). Although not shown in Table 13, a remediation scenario is also addressed (Section 5.3.3), which is assumed to last for a period of two months. Thus, the active project time estimated for the remediation scenario is one sixth (2/12) of the active project time estimated for the year-long construction project.

5.3.3 Estimating exposure to dust

Table 14 presents exposure estimates that result from inputting the parameter values from Table 13 into the corresponding emission and dispersion models (described in Section 5.3.1). In Table 14, the first column indicates the specific activity modeled. The second column indicates the emission rate derived by inputting the parameter values from Table 13 into the various emission models. The corresponding instantaneous dust concentrations generated at the receptor for each listed activity is provided in the third column of Table 14.

To illustrate how dust emission rates and the corresponding, instantaneous dust concentrations in Table 14 are derived, consider the case for exposure associated with walking over contaminated soil. The emission and dispersion models used to evaluate walking over soil are described in Table 8. Substituting the input values described in the column headed "walking" in Table 13 into the emission model presented at the top of Table 8 results in the following:

$$2.4\text{x}10^{-2}\ (\text{g/sec}) = 1.7*(0.278)*(0.35)*(38/12)*(6^2/48)*(0.073/2.7)^{0.7}*(2.4/4)^{0.5}/(0.2/0.2)^{0.3}.$$

Noting that the output emission rate indicated for the equation at the top of Table 8 is in g/sec and that the emission rates listed in the second column of Table 14 are in kg/sec and making the requisite conversion (i.e. dividing the value indicated in the above equation by 1000), we see that the above equation indeed returns the emission rate presented in Table 14 for walking.

To estimate the instantaneous concentration (of respirable dust) generated in association with walking over contaminated ground, it is simply necessary to multiply the above-derived emission rate by the dispersion portion of the equation listed at the bottom of Table 8. Thus:

$$0.00078\ (\text{g/m}^3) = 2.4\text{x}10^{-2}*[1/\{(3)*(1.75)*(3)\}]*[(0.5)+\{1-(0.5)\}*(0.01)].$$

Noting that the instantaneous concentrations listed in Table 14 are reported in mg/m^3 and the output for the equation above is in g/m^3, one must multiply the above value by 1000 before comparing to the value listed for walking in the third column of Table 14. In this case, there remains a small difference (in the second significant figure) between what is calculated using the above equation and what is presented in Table 14. This is due to a rounding error because the spreadsheet preserves additional significant figures for intermediate calculations that have been truncated in the equations presented on this page.

Note, after dividing the emission and dispersion equation at the bottom of Table 8 by the emission equation at the top of that table, the remaining terms include, $R_{a/d}$ and the dispersion-related terms that have been incorporated into the equation listed prior to the last paragraph above to calculate the instantaneous dust concentration. As indicated in Table 8 and the accompanying text (Section 5.3.1)**,** the term, $R_{a/d}$, represents the concentration of asbestos in source material and is used later to convert estimated dust exposure concentrations to asbestos exposure concentrations, which will be addressed in detail in Section 5.3.4.

The dust concentrations listed in the third column of Table 14 represent *instantaneous* concentrations. This means they are concentrations that develop only while each activity is actually being conducted. While continuous, lifetime estimates of exposure are needed to assess risks to carcinogens, none of the activities indicated in Table 14 could ever be conducted continuously over an entire lifetime. Therefore, the concentrations listed in the fourth column of Table 14 have been adjusted for duration and frequency to derive reasonable exposure point concentration estimates that can be used to support a risk assessment addressing asbestos.

Table 15 presents estimates of the durations and frequencies with which each of the activities of interest are typically conducted. With a small number of exceptions, these were obtained from the Exposure Factors Handbook (U.S.EPA 1997).

The first column of Table 15 lists the specific activities of interest. The second and third columns indicate, respectively, the number of hours/day and the number of days/year over which each activity is assumed to be conducted. The next column of the table indicates the fraction of a year represented by such frequencies, which is determined as:

Fraction of year = (hours/day x days/year)/(hours in a year).

The fifth column of Table 15 indicates the duration (in number of years) over which each activity is assumed to be conducted. The sixth column of the table indicates the fraction of a lifetime spent conducting each activity (as represented by the corresponding duration and frequencies of each activity). Thus, the fraction of a lifetime for a specific activity is determined as:

Fraction of lifetime = (hours/day * days/year * number of years)/(hours in a lifetime).

Note that the number of hours in a lifetime employed in the above equation is determined by assuming that a lifetime is 70 years long so that the number of hours in a lifetime is simply $24*365*70 = 6.132X10^5$.

The last two columns of Table 15 indicate, respectively, a reference for the source of the estimated durations and frequencies for each activity and the areas over which each activity is most likely to be conducted.

Except for handling ACM, rototilling, ATV riding, and construction-related pathways, the durations and frequencies assumed for the other pathways all represent upper-bound estimates derived from a review of the Exposure Factors Handbook (U.S.EPA 1997). Because there are no relevant values in the Exposure Factors Handbook, the durations and frequencies of exposure associated with playing with ACM were estimated based on professional judgment, as described below. Because there are no relevant values in the Exposure Factors Handbook for rototilling, the default values used by the U.S.EPA for the Libby site (U.S.EPA 2001) were employed here. The duration and frequency estimated for ATV riding are based on professional judgment and account only for hours that an ATV might be driven locally around the neighborhood (as opposed to times during which other remote locations set aside for ATV use might be visited).

Two sets of durations and frequencies were assumed for construction-related pathways. The first is based on an assumed future project involving commercial construction of additional housing. In this case, it is assumed that such activities would last a year and would be conducted at occupational frequencies (8 hrs/day for 250 days/yr). This should be conservative for almost any type of commercial construction or maintenance activity (including utility work) that might potentially be conducted at the site in the future.

The second construction-related scenario was designed to represent a remediation project in which the ACM-burial sites on the property are excavated (or stabilized). For this scenario, a duration of 2 months is assumed. As with the commercial construction scenario above, work during remediation is assumed to continue for 8 hours/day and 250 days/year. In this case, the 250 days per year is divided by 6 (to account for a two-month duration).

To estimate the duration and frequency with which ACM might be handled, it was considered unlikely that children or adults would regularly handle ACM for an average of more than an hour a day and such activities are unlikely to be repeated regularly over the course of a year. In fact, it seems unlikely that individuals would handle ACM as much as once per week, as estimated in the table. Moreover, the regular handling of ACM was assumed largely limited to younger children (approximately between the ages of 2 and 15) with a couple of additional years added for later encounters so that the total duration over which this activity might occur was assumed to extend about 15 years. Children younger than 2 are not likely to have regular access to such materials. Except for very rarely, children older than 15 are likely to engage primarily in activities other than those that might encourage regular handling of ACM. Adults are only likely to handle ACM when they encounter large pieces that they wish to remove from interfering with other activities and these would also likely be rare events.

Perhaps most important, the simple handling of ACM is unlikely to substantially abrade such material. Thus, most of the time that ACM is handled, the associated exposures would be much smaller than that estimated in the scenario presented here (in which the ACM is intentionally abraded by scraping on pavement); the duration and frequency with which individuals conduct activities that forcefully abrade ACM is likely substantially smaller than the estimates employed in this study. Therefore, the time estimates assumed for this activity are conservative.

With the exception of playing with ACM, rototilling, ATV riding, and construction-related activities (which are discussed above), because the upper-bound estimate of the total time individuals tend to spend outdoors is applied to each of the activities listed, neither exposures nor the attendant risks estimated for these activities should be summed. Rather, a conservative estimate of the exposure or risk associated with any of these activities is simply equivalent to the largest of the estimated exposures or risks derived for any individual activity, which is interpreted as the “worst case” individual conducting the dustiest of the indicated activities solely and continuously for the entire (conservative estimate of the total) time that such an individual is active outdoors.

It should also be emphasized that, even if exposures were to be summed, the differences between the largest of the individual estimates and the summed values would be less than a factor of two, due to the disparity of the estimated risks for individual exposure pathways. This is typical of most risk assessments; it is unusual for more than two or three pathways to contribute substantially to summed values.

The time averaged dust exposure concentrations presented in the fourth column of Table 14 are derived simply as the product of the instantaneous concentrations presented in the third column of this table and the fraction-of-a-lifetime estimates Indicated for the corresponding activity in the sixth column of Table 15. Thus, to illustrate using walking:

$$2.7\text{x}10^{-2}\ \text{mg/m}^3 = 7.8\text{x}10^{-1}\ \text{mg/m}^3\text{*}0.034\ \text{(unitless)}.$$

As the time-averaged dust exposure concentrations presented in the fourth column of Table 14 represent lifetime average exposures, these estimates are appropriate for supporting risk assessment for carcinogens.

5.3.4 Estimating exposure point concentrations of asbestos

Asbestos exposure point concentrations for specific exposure pathways are each estimated simply by multiplying an appropriately selected asbestos concentration in source material and the corresponding, time-averaged dust exposure concentration estimated for each exposure pathway of interest (Column 4 of Table 14). Asbestos concentrations observed in various source materials at the North Ridge Estates site are presented in Table 16[20]. The corresponding exposure point concentrations for asbestos are summarized and discussed in Section 5.5 below.

[20] With one exception, the data in Table 16 are derived from the measurements presented in Table

In Table 16, the first column indicates the set of samples (types of source material) from which each concentration estimate is drawn. The next three columns indicate, respectively, the estimated concentration of protocol structures, the fraction of protocol structures longer than 10 µm, and the concentration of 7402 structures.

With one exception, the concentrations presented in Table 16 all represent conservative, upper bound estimates. In many cases, as indicated in the table, the maximum of a set of measurements is employed to represent the concentration in a particular matrix. The maximum value observed among the individual measurements is employed when the data set evaluated is shown not to be statistically consistent (Table 5, Section 4.1.4).

Because measurements of asbestos concentrations in composite soils were shown to be statistically consistent (Table 5), a formal upper bound was estimated specifically for this data set. Thus a 95% upper confidence limit (95% UCL) to the mean of the concentrations observed among soil composites was appropriately determined from a Poisson distribution (see discussion of Poisson distributions in Section 4.1.2). To calculate a 95% UCL in this case, the 95% UCL based on a Poisson distribution (5 structures) is determined for the total number of structures observed across all of the samples (1 structure) and the 95% UCL from the Poisson distribution is multiplied by the pooled analytical sensitivity for the sample set evaluated. In turn, the pooled analytical sensitivity is calculated as the reciprocal of the sum of the reciprocals of the analytical sensitivities for the 10 individual samples in this set. As indicated in Table 1, the analytical sensitivity for each of the 10 individual samples is approximately 2×10^6 str/g_{PM10}. Thus, the pooled analytical sensitivity (2×10^5) is determined as:

$$2 \times 10^5 = 1/\{10*[1/(2 \times 10^6)]\}$$

Thus, the 95% UCL concentration estimated for these samples is 1×10^6 str/g_{PM10} (5 structures x 2×10^5 analytical sensitivity), which must be divided by one million so that the units are adjusted to str/μg_{PM10} to compare it to the value in Table 16. Note that the value reported in Table 16 (0.9) is slightly lower than the value estimated here (1.0) because the calculation presented here includes truncated estimates of analytical sensitivity that are rounded to the nearest whole value whereas the values in Table 16 are not based on truncated estimates. Thus, this difference is due to rounding.

---

6 with the specific columns of Table 6 selected based on the type of source material under consideration. Thus, for example, asbestos concentrations in soil components alone are provided in Columns 5 through 7 of Table 6. For asbestos concentrations in soils contributed by the embedded ACM, the data in Columns 11 through 13 are employed. Total asbestos concentrations in soils (with contributions from the embedded ACM included) are presented in Columns 14 through 16 and the concentrations of asbestos observed in pure ACM are provided in Columns 8 through 10. An explanation of the derivation of these concentration estimates is provided in Section 4.2. Regarding the one exception, asbestos concentrations observed in steam-pipe insulation that are reported in Table 16 are derived from analysis of a composite sample collected from material recently observed at the site, which is not included in Table 6.

Regarding the one exception to the presentation of conservative concentration estimates in Table 16, concentrations indicated in the table for asbestos in steam-pipe insulation (MAG ACM) are based on results from analysis of a single, composite sample that was collected to represent the nature of the material observed in three locations on site just after the spring thaw earlier this year.

The concentrations presented in the top portion of Table 16 represent concentrations of chrysotile structures, which account for the vast majority of the asbestos observed on site. During the initial sampling of the site (as discussed in Section 4), only a single sample (from among 18 soil samples and 13 ACM samples analyzed from the site) exhibited observable concentrations of any type of asbestos other than chrysotile. In the sample representing the soil component from Hot Spot 6, several amosite structures were observed in addition to chrysotile.

Concentrations of amosite asbestos structures observed in the soil component of Hot Spot 6 and in the composite sample of steam-pipe insulation (collected from material observed on site following the recent, spring thaw) are presented in the lower, shaded portion of Table 16. Although observed only rarely in isolated areas of the site, the presence of amosite (an amphibole asbestos) is explicitly addressed in the following risk assessment because amphibole asbestos is believed to be more hazardous (fiber-for-fiber) than chrysotile (Berman and Crump 2001).

The various concentration estimates presented in Table 16 are each appropriate for different exposure pathways. In many cases, they may even be considered to be bounding estimates, as long as the types of asbestos (chrysotile or amphibole) are addressed separately. Both because chrysotile and amphibole asbestos exhibit differential potencies and because they are derived from different materials exhibiting different distributions at the site, they are addressed separately below.

5.3.4.1 Estimating exposure point concentrations for chrysotile

The chrysotile concentration estimates presented in the upper rows of Table 16 are each employed to estimate source concentrations for each of the exposure pathways evaluated in this report. Thus, for example, the mean and upper 95% confidence limit estimate for the concentrations of chrysotile structures in composite surface soils without ACM[21] (which are listed in the first and second rows of the table, respectively) are appropriate for exposure pathways involving disturbance of surface soils over large areas of the site where ACM has been physically removed from site soils.

Because new ACM was observed in many previously cleaned areas of the site this spring (Judy Smith of U.S.EPA, Memorandum dated April 21, 2004, Subject: *Seeking Access to Walk Site Next Week*), the maximum chrysotile concentrations observed in

[21] These concentrations are derived from the concentrations observed among the soil components of these samples (Columns 5 to 7 of the first 11 rows of Table 6). Thus, the contributions from any ACM that was present are not included.

composite samples (with the contribution from embedded ACM included – Row 4 of Table 16) are used in the following risk assessment to represent source concentration estimates in surface soils appropriate for exposure pathways involving walking, running, bicycling, and ATV riding. These are pathways that are typically conducted over large areas of the site. Moreover, as indicated in Appendix F, the bounding estimates presented in Row 4 for the composite sample set of the current study (with ACM contributions included) are also shown to be bounding for the U.S.EPA sample set which, in turn, represents "worst case" conditions for each individual residence. Therefore, these source concentration estimates for chrysotile should be considered to be bounding even if these activities are conducted only over individual residential areas.

Note that the reappearance of ACM in previously cleaned areas is likely due to uplift from freeze-thaw cycling and, as such, was not unexpected (for example, see Berman 2003c, Page 4).

Rototilling is also generally conducted over relatively large areas of a site, although such areas may be somewhat more limited than the areas over which walking, running, bicycling, or ATV riding are typically conducted. Moreover, rototilling involves excavation into the shallow sub-surface so that bounding source concentrations relevant to rototilling may be somewhat different than those employed for these other pathways. Nevertheless, the bounding concentrations estimated from the composite samples of the current study (including contributions from embedded ACM) were shown to bound the U.S.EPA data and, in turn, the U.S.EPA data are expected to be conservative for exposures within residential lots. This suggests that the same bounding source concentrations of chrysotile that are used for walking, running, bicycling, and ATV riding (see above) should also be appropriate for rototilling.

Note that a data gap that may be useful to fill, depending on the need to assess rototilling in a more sophisticated manner in the future, might be to collect data suitable for evaluating the vertical profile of asbestos contamination in the shallow sub-surface.

Gardening and children playing potentially represent localized activities and may involve the disturbance of shallow sub-surface soils, from which ACM may not have been removed. Therefore, to be conservative, the chrysotile concentrations selected for assessing exposure via these pathways is the maximum of the concentrations observed anywhere onsite, including hot spots (Row 5 of Table 16)[22]. Moreover, both the contributions from structures observed in the soil component and in the ACM component of this sample are included in the determination of these concentrations. Because it is unlikely that individuals would garden in locations where high concentrations of ACM are buried (i.e. the hot spots), use of these concentration estimates are considered to be extremely conservative, bounding estimates for chrysotile concentrations relevant to these pathways, no matter where they are conducted on the site.

[22] These concentrations are presented in the last three Columns of Table 6. Their derivation is described in Section 4.2.

For exposure pathways involving commercial construction, the maximum chrysotile concentrations observed among composite samples, including contributions from ACM (Row 4 of Table 16) are considered appropriate. This is because construction activities are likely to be conducted over large areas of the site and only extremely limited time would be expected to be spent in any particular hot spot area. In case ACM contamination extends beneath the surface at the site, the combined contributions from both the soil and ACM components of these samples are included. Thus, the concentrations presented in Row 4 are expected to be extremely conservative, bounding estimates for these pathways.

As previously indicated (Section 5.3.3), a remediation scenario is also considered for construction activities. The chrysotile concentrations assumed for the remediation scenario are the maximum concentrations of chrysotile observed among the hot spot samples with contributions from the ACM components included (Row 5 of Table 16). These are expected to be conservative, bounding estimates even for a remediation scenario.

To evaluate exposure associated with the handling of chrysotile-containing ACM, the concentrations of asbestos in the source material were conservatively estimated as the maximum of the concentrations of structures observed among the ACM component of any sample (Row 6 of Table 16, for chrysotile). These should represent bounding estimates of concentration for this pathway.

5.3.4.2 Estimating exposure point concentrations for amphibole asbestos

To assess potential contributions from the presence of amphibole asbestos to overall exposure and risk, the amphibole asbestos concentrations reported in the shaded portion of Table 16 (for the two matrices in which amphibole asbestos was observed in this study) are considered along with the results of an evaluation to estimate the relative occurrence of amphibole asbestos at the North Ridge Estates Site (Appendix F). The evaluation in Appendix F is based on observations gleaned from data reported both in this study and other soil measurements from the site recently reported by U.S.EPA (Wroble, private communication). The soil measurements reported by U.S.EPA are also compared with results from this study to evaluate the overall consistency of the two data sets.

Importantly, while the hot spots chosen for sampling in both the current study and the U.S.EPA study are appropriate for bounding source concentrations for chrysotile, they may not necessarily bound potential exposures to amphibole asbestos for every exposure pathway of interest. Due to the relatively greater potency assumed for amphibole asbestos compared to chrysotile asbestos (Section 5.4), relatively lower concentrations or, correspondingly, higher concentrations encountered less frequently than chrysotile might still pose a potential concern.

Certainly the existing data indicate that the chance of encountering amphibole is extremely rare (see Appendix F). At the same time, given the observation that three small areas of the site were recently encountered over which steam-pipe insulation was observed and removed, it is possible that other isolated areas of the site also harbor elevated levels of amphibole asbestos. Therefore, it will likely be necessary to further bound the low concentrations of amphibole asbestos that was detected and to further refine the site model to assure that potential amphibole asbestos-containing hot spots are adequately identified and addressed

Source concentrations for amphibole asbestos were estimated from the existing data in a manner similar to that described for chrysotile. Given the above, however, the uncertainties of the existing dataset are considered as part of the risk assessment (Section 5.5.2) and discussed in the uncertainty analysis that is also presented (Section 5.6).

To assess amphibole asbestos exposure associated with walking, running, bicycling, and ATV riding (which tend to be conducted over large areas of the site), upper bound estimates of averaged conditions are assumed as source concentrations. These have been derived within the uncertainty of the existing data set in the manner described below.

Because, as indicated in Appendix F, the only place where amphibole asbestos structures that are sufficiently long to be considered biologically active were detected was in a single hot spot collected from a hole in a foundation, the concentrations from this hot spot should not be considered to be representative of any extended surface area of the site. Moreover, as indicated above, the only locations where amphibole asbestos-containing ACM (e.g. steam-pipe insulation) was observed on the surface has been cleaned up. Thus, to estimate source concentrations appropriate for exposure pathways typically conducted over extended areas, it is conservatively assumed that the two short amphibole asbestos structures observed among the U.S.EPA samples infer the possible presence of biologically active structures representing a low, general level of amphibole contamination and an upper bound estimate of the concentrations of such amphibole asbestos was derived as described in Appendix F. It is these upper bound estimates of concentration for structures that were not even detected ($2x10^5$ s/g_{PM10}) that are employed to evaluate amphibole-related risks from walking, running, bicycling, and ATV riding.

As previously indicated, rototilling is also generally conducted over relatively large areas of a site, although such areas may be somewhat more limited than the areas over which walking, running, bicycling, or ATV riding are typically conducted. Moreover, rototilling involves excavation into the shallow sub-surface so that bounding source concentrations relevant to rototilling may be somewhat different than those employed for these other pathways. Nevertheless, for the same reasons indicated in the last paragraph, it appears that the best available estimates for source concentrations of amphibole asbestos that are appropriate for rototilling are the same concentrations estimated for walking, running, bicycling, and ATV riding.

Note that, as previously indicated, the lack of data suitable for evaluating the vertical profile of asbestos contamination (for either chrysotile or amphibole asbestos) in the shallow sub-surface represents a data gap that may be useful to fill, depending on whether a need arises for reevaluating the risks associated with rototilling in the future. One other consideration also needs to be addressed specifically with regard to amphibole asbestos. There is no evidence that hot spots containing amphibole asbestos actually exist at the surface or in the near-surface soils of the site and current data suggests that any such occurrence is at best extremely rare. However, depending on how risk is ultimately managed at this site, there may be a need to better evaluate the potential that amphibole asbestos-containing ACM might be exposed in the future;

Gardening and children playing potentially represent localized activities and may involve the disturbance of shallow sub-surface soils, from which ACM may not have been removed. Therefore, to be conservative, the amphibole asbestos concentrations selected for assessing exposure via these pathways is the maximum of the concentrations observed anywhere onsite, including hot spots (the first row of Table 16 under the heading, "Amosite"). Moreover, both the contributions from structures observed in the soil component and in the ACM component of this sample are included in the determination of these concentrations. As long as hot spots containing amphibole asbestos do not become exposed (see discussion above), these concentrations appear to be reasonably conservative estimates for amphibole asbestos concentrations that might be encountered when adults garden or children play in local soils.

Importantly, neither children playing nor adults gardening are likely to penetrate to the depths sufficient to encounter undisturbed, buried steam pipe (approximately 2 ft), except, potentially, for the isolated areas where such pipe historically came to the surface to enter structures near foundations of old buildings. To the extent not already addressed, any such areas should therefore be identified and managed.

For exposure pathways involving commercial construction, which occur only over very large areas of the site, it is conservatively assumed that the two short amphibole asbestos structures observed among the U.S.EPA samples infer the possible presence of biologically active structures representing a low, general level of amphibole contamination and an upper bound estimate of the concentrations of such amphibole asbestos was derived as described in Appendix F. It is these upper bound estimates of concentration for structures that were not even detected ($2x10^5$ s/g_{PM10}) that are employed to evaluate amphibole-related risks from construction-related activities.

The amphibole-asbestos concentrations derived from Hot Spot Sample No. 6 (which is presented in the first row of Table 16 under the heading, "Amosite") were used to represent source concentrations for the remediation scenario that is also considered in this report (Section 5.3.3). As this was the only sample in any data set in which amphibole asbestos structures within the range considered to be biologically active (Section 5.4) were observed, this is expected to represent a reasonably conservative estimate for amphibole-asbestos concentrations that might be encountered over the course of any site remediation that might extend as long as two months. Although it is possible that higher concentrations of amphibole asbestos might be encountered in small, isolated areas of the site, it is unlikely that the time over which work would be conducted in such areas would constitute more than an extremely small fraction of the total time over which the remediation scenario is assumed to occur.

To evaluate exposure associated with the handling or abrading of amphibole asbestos-containing ACM, the concentration of asbestos in the source material was conservatively estimated as the maximum of the concentrations of structures observed among the ACM component of any sample (the second row under the heading, "Amosite" in Table 16). This should represent a bounding estimate of concentration for this pathway.

5.4 Assessing Toxicity

Asbestos-related risks are estimated in this document by combining exposure estimates with exposure-response coefficients derived from each of two separate protocols. The first is a new protocol developed by Berman and Crump (2001). The second is the approach currently recommended by the U.S.EPA (IRIS 1988).

The Berman and Crump (2001) protocol was recently subjected to a peer-review consultation by the U.S.EPA and received favorable reviews (ERG 2003). Based on the recommendations of the panel, the report was finalized and is now being distributed by EPA while the additional research that was recommended by the panel to refine some of the details is being conducted. Thus, as a conservative, interim step, both approaches are employed in this study to assess toxicity and risk.

In both cases, risk will be estimated as the product of time-averaged exposure concentration estimates and, appropriately matched, unit risk factors.

5.4.1 Adapting Unit Risk Factors from Berman and Crump 2001

Unit risk factors (URF's) for asbestos are derived for use in this evaluation from asbestos risk estimates provided in Table 8-1 of Berman and Crump (2001), which is reproduced here as Table 17. The procedure described below, which was used to derive URF's from the risk estimates presented in Berman and Crump, is identical to the procedure used to derive the URF for asbestos that is currently recommended by EPA (IRIS 1988, see Section 5.4.2).

Table 17 presents estimates of the additional risk of death from lung cancer and mesothelioma attributable to lifetime exposure at an asbestos concentration of 0.0005 s/cm^3 (for total protocol structures) as determined based on counts derived using the rules of ISO Method 10312 (ISO 1995). In the table, separate risk estimates are presented for exposures containing varying fractions (in percent) of protocol structures longer than 10 μm. Separate estimates are presented for smokers and nonsmokers because the lifetime asbestos-induced risk of both lung cancer and mesothelioma differ between smokers and non-smokers. Separate risk estimates are also provided for men and women.

As suggested in Table 17, the asbestos-induced risk of lung cancer is higher among smokers. This is because the model used to develop the table incorporates a multiplicative effect between smoking and asbestos exposure (Berman and Crump 2001). The asbestos-induced risk of mesothelioma is smaller among smokers because the time-dependent power curve incorporated into the model for mesothelioma places greatest weight on risk among the elderly and smokers do not live long enough to contribute as much to risk in this age range.

The URF's are developed based on the following assumptions:

- 21.4 percent of the U.S. population smokes; and
- 50 percent of the U.S. population is male.

URF's are also developed assuming a specific fraction of protocol structures are longer than 10 μm.

To develop an asbestos URF, first, a population averaged risk factor, R_{pop}, is generated. Because Berman and Crump assign different potencies to the two major types of asbestos, a separate R_{pop} is generated for chrysotile and for amphibole asbestos. Using the combined risk values (which accounts for both lung cancer and mesothelioma), one calculates:

$$R_{pop} = 0.5*[0.786*(NSM+NSF) + 0.214*(SM+SF)]$$

Where (for chrysotile with 50 percent of protocol structures longer than 10 μm):

NSM is the combined risk factor listed in the chrysotile part of Table 17 for non-smoking males in the column for 50 percent long protocol structures;

NSF is the combined risk factor listed in the chrysotile part of Table 17 for non-smoking females in the column for 50 percent long protocol structures;

SM is the combined risk factor listed in the chrysotile part of Table 17 for smoking males in the column for 50 percent long protocol structures; and

SF is the combined risk factor listed in the chrysotile part of Table 17 for smoking females in the column for 50 percent long protocol structures.

Note that the coefficients in the above equation: 0.786 and 0.214 simply represent the fraction of smokers and non-smokers, respectively, in the U.S. population.

The same equation holds for amphibole asbestos except that the corresponding values for amphibole asbestos from Table 17 are substituted into the equation rather than the values for chrysotile.

Finally, the new, integrated risk estimate is converted to a URF by multiplying it by the target risk value to convert the values listed in the table to risk values and dividing by the reference exposure concentration. As indicated in the title of Table 17, the reference risk value is $1x10^{-5}$ (one in one hundred thousand) and the reference concentration is 0.0005 str/cm^3. Thus:

$$URF = (10^{-5}/0.0005)*(R_{pop})$$

Note that the above equation is just the equation for using URF's to assess risk, but is solved for URF:

$$Risk = URF*Concentration.$$

Moreover, the units are correct.

The resulting URF's for chrysotile and amphibole asbestos, respectively, are listed in Table 18 of this document. Note that they are developed assuming lifetime, continuous exposure, which is equivalent to an averaging time of 70 years x 365 days/year x 24 hours/day x 60 minutes/hour x 60 seconds/minute = $2.2x10^9$ sec (or $6.1x10^5$ hours). Note also that URF's have been derived for several assumed distributions ranging between 1 percent and 100 percent of structures longer than 10 µm.

Importantly, the risk estimates presented in Berman and Crump (2001) and therefore the URF's derived from these estimates are adjusted to be matched to exposure concentrations expressed in terms of "protocol structures." These are structures longer than 5 µm and thinner than 0.5 µm with the fraction of structures longer than 10 µm separately enumerated. Risks can thus be estimated simply as the product of a time-averaged exposure point concentration estimate (expressed as the concentration of protocol structures) and the appropriate URF (chosen for the type and size distribution of structures). However, it is NOT appropriate to combine URF's derived from Berman and Crump (2001) with concentrations estimated for any other size range of asbestos structures than those satisfying the dimensional criteria defined for protocol structures. Nor is it appropriate to apply URF's derived for amphibole asbestos to concentrations representing structures of chrysotile (or the reverse).

5.4.2 Adapting the Unit Risk Factor from IRIS 1988

The URF used in the traditional approach for assessing risk currently recommended by U.S.EPA (IRIS 1988) is also provided in Table 18. This URF is designed to be applied to asbestos structures satisfying the dimensional criteria for 7402 structures (PCME structures). These are structures longer than 5 µm and thicker than 0.25 µm that exhibit largely parallel sides and also exhibit an aspect (length to width) ratio greater than 3. Note that all asbestos mineral types are considered equipotent in the traditional approach to asbestos risk assessment. Therefore, the URF from IRIS (1988) is applicable to both amphibole and chrysotile.

The URF from IRIS (1988) is employed to estimate risk in a manner identical to that described for the URF's derived from Berman and Crump 2001 (Section 5.4.1).

5.5 Assessing Risk

Risks attendant to exposure to chrysotile (the primary type of asbestos found at the site) and to amosite (an amphibole asbestos) are considered separately in the following discussion and the estimated contributions to risk from each of the asbestos types are then combined, although the validity of combining these estimates is unclear given that both sets of estimates are already extremely conservative, bounding estimates. Moreover, the amphibole-asbestos related risks for several of the exposure pathways considered in this assessment are derived from conservative, bounding estimates of non-detected (biologically active) structures, whose presence is inferred from observations of a total of two short structures observed among 22 samples (Appendix F). As already indicated (Section 5.3.3), summing across risks only tends to change estimates of risks by at most a factor of two or three (in this case, no more than two), which represents a minor adjustment relative to effects from other factors.

The adequacy of the sampling effort is also considered in this assessment. Due to differences in the relative potencies of the two fiber types (chrysotile and amphibole asbestos), the nature of the sampling effort affects conclusions concerning each fiber type in different ways. These considerations are also addressed further in the following discussion of uncertainties.

5.5.1 Assessing chrysotile-related risks

Activity-specific exposures and the attendant risks estimated for chrysotile are summarized in Table 19. In Table 19, the specific exposure pathways evaluated are listed in the first column. The second column lists the time-averaged dust exposure concentrations estimated for each pathway. These are reproduced from the fourth column of Table 14.

Chrysotile concentrations determined in soils (source materials) at the site that are appropriate for each of the exposure pathways of interest are presented in the third and fourth columns of Table 19 for protocol structures and 7402 structures, respectively. These are reproduced from Table 16 and selected in the manner described in Section 5.3.4. As indicated in Section 5.3.4, each of the estimated source concentrations represent conservative, upper bounds for the conditions represented.
Exposure point concentrations for chrysotile are presented in the fifth and sixth columns of Table 19 for protocol structures and 7402 structures, respectively. These are determined as the product of the source concentrations of asbestos and the time-averaged dust concentrations for the corresponding exposure pathways.

The last two columns of Table 19 present the risks attendant to the exposure point concentrations of chrysotile, which are estimated for protocol structures and 7402 structures, respectively. In the table, risks that are estimated to exceed $1x10^{-4}$ (one in ten thousand) are highlighted. These estimates exceed the upper end of the risk range (10^{-6} to 10^{-4}) that is potentially considered acceptable by U.S.EPA when site-specific conditions are addressed. However, this does not automatically indicate that the actual risks associated with any particular pathway should be considered unacceptable. The implications of the risk estimates presented in these tables are addressed below for each of the exposure pathways listed in the risk tables.

Importantly, as previously indicated, this report is intended as a preliminary risk assessment so that a relatively simple, extremely conservative, bounding analysis was conducted to assess risk. Therefore, while it is proper to conclude from these estimates that risks are acceptable, a more sophisticated evaluation would need to be conducted before any risks that are estimated to be unacceptable are reasonably concluded to be unacceptable. . Moreover, unless risks are substantially higher than the upper end of the range (perhaps at least an order of magnitude higher), they clearly do not represent imminent hazards requiring immediate action. Thus, risks that are estimated to be less than 10^{-3} indicate that it is legitimate to spend the time required to adequately study the problem before deciding on the need for remediation. Expeditious removal actions are not required in these cases.

Risks associated with residential exposure pathways and worker exposure pathways are separately addressed below.

5.5.1.1 Assessing risk associated with activities by local residents

As can be seen in Table 19, none of the risks estimated for residential pathways involving walking, running, bicycling, rototilling, gardening, or children playing in dirt exceed the upper end of the risk range potentially considered acceptable by U.S.EPA when risks are estimated based on either protocol structure concentrations or 7402 structure concentrations. In contrast, the risk estimated for abrading ACM slightly exceeds the upper end of the risk range, as does the risk estimated for riding ATV's over the site. Risks from each of these pathways are addressed in greater detail below.

Walking, Running, and Bicycling

The chrysotile-related risks estimated for walking, running, and bicycling in Table 19, assume that such activities will be conducted over large areas of the site that are represented by upper bound estimates of averaged conditions (see Section 5.3.4). For this case, as previously indicated, the maximum concentration observed among composite samples with contributions from any embedded ACM included (Table 16, Row 4) were employed as estimates of source concentrations for chrysotile. Use of such concentrations for these pathways is expected to be conservative because they are upper bound estimates and these activities tend to be conducted over large areas. Moreover, as indicated in Appendix F, the concentration estimates employed here also exceed the maximum concentration reported in the U.S.EPA soil study, which was designed to represent worst-case conditions within the specific, residential properties of the site. Further, the concentrations estimated here assume that any embedded ACM has completely degraded and released all of its available asbestos structures, a condition that will not likely occur for many years, if ever.[23]

The exposure and risk estimates for these pathways are also expected to be highly conservative due to the manner in which they were modeled (Section 5.3.1) coupled with the use of multiple, conservative estimates of the values for the input parameters required for each model (Section 5.3.2). This is particularly true for walking, running, and bicycling where the model employed actually predicts exposures to hypothetical individuals who would constantly travel immediately behind and downwind of the individual who is walking, running, or bicycling. Exposures (and the attendant risks) to walkers, runners, or bicyclists from their own plume would be substantially smaller (see Section 5.3.1).

Despite the degree to which the risk estimates for these pathways represent conservative upper bounds, the risks presented in Table 19 fall within the risk range potentially considered to be acceptable by U.S.EPA. Thus, chrysotile-related risks posed to residents during walking, running, or bicycling across neighborhood soils fall within the range potentially considered acceptable by U.S.EPA on a site-specific basis.

Gardening and Children Playing in Soils

The risks estimated for gardening and children playing in soils that are presented in Table 19 should also be considered to be extremely conservative because they are based on source concentrations set equal to the maximum observed concentration in hot spot soils with contributions from ACM included (Row 5 of Table 16). It is unlikely that such activities would be conducted at any obvious hot spot (where ACM exists in sufficient quantities to present a physical obstacle to digging and where such ACM is certainly readily apparent). Even if such hot spots were occasionally to be disturbed during such activities, the conditions at such locations would not be representative of the averaged conditions experienced during such activities over the long-term.

These risk estimates should also be considered conservative due to the multiple, conservative assumptions incorporated into the exposure modeling (see Section 5.3.2). Despite the degree to which the risk estimates for these pathways represent conservative upper bounds, the risks presented in Table 19 fall within the risk range potentially considered to be acceptable by U.S.EPA. Thus, chrysotile-related risks posed to residents during gardening or children playing in local soils fall within the range potentially considered acceptable by U.S.EPA on a site-specific basis.

Handling and Abrading ACM

---

[23] If ACM contributions are discounted (due to lack of complete degradation) or if ACM is ultimately and permanently removed from surface soils at the site, then source concentrations (and the attendant exposures and risks) for walking, running, and bicycling will likely drop by approximately a factor of 20 (i.e. to levels associated with the UCL estimate of the mean concentration observed in composite samples without contributions from the embedded ACM Table 16, Row 2).

As indicated in Table 19, the risk estimated for the exposure pathway involving abrasion of chrysotile-containing ACM slightly exceeds the upper end of the range of values potentially considered acceptable by the U.S.EPA. However, the risk estimate presented in the table for this pathway is likely conservative both because it incorporates an assumption that ACM containing the highest observed concentration will be handled and because several conservative assumptions were incorporated into the modeling of exposure for this pathway, including the assumption that the ACM will not only be handled, but will be intentionally abraded by physically scraping it against concrete. Therefore, in contrast, if chrysotile-containing ACM is simply picked up and handled (as opposed to actively abraded), the attendant risks should be substantially lower and would likely remain within the acceptable range. Depending on needs, a more sophisticated evaluation of this pathway may be incorporated into the final risk assessment for the North Ridge Estates Site.

Rototilling

The chrysotile-related risks estimated for rototilling that are presented in Table 19 fall within the range potentially considered acceptable by U.S.EPA. These risk estimates are assuming this activity will be conducted over large areas of the site that are represented by upper bound estimates of averaged conditions (see Section 5.3.4). For this case, as previously indicated, the maximum concentration observed among composite samples with contributions from any embedded ACM included (Table 16, Row 4) were employed as estimates of source concentrations for chrysotile. Use of such concentrations for this pathway is expected to be conservative because they are upper bound estimates and this activity tends to be conducted over large areas. Moreover, as indicated in Appendix F, the concentration estimates employed here also exceed the maximum concentration reported in the U.S.EPA soil study, which was designed to represent worst-case conditions within the specific, residential properties of the site. Further, the concentrations estimated here assume that any embedded ACM has completely degraded and released all of its available asbestos structures, a condition that will not likely occur for many years, if ever.[24]

The modeled exposure and risk estimates for this pathway are also extremely conservative due to the other conservative inputs employed to model exposure. For example, rototilling was assumed to be conducted only under the driest, dustiest conditions on soils containing the highest observed fraction of silt.

Despite the degree to which the risk estimates for this pathway represent conservative upper bounds, the risks presented in Table 19 fall within the risk range potentially considered to be acceptable by U.S.EPA. Thus, chrysotile-related risks posed to residents while rototilling across residential soils fall within the range potentially considered acceptable by U.S.EPA on a site-specific basis.

[24] Ibid.

ATV-riding

The risks estimated for ATV-riding in Table 19 slightly exceed the upper end of the risk range (10^{-6} to 10^{-4}) that is potentially considered acceptable by U.S.EPA when site-specific conditions are addressed. However, these risk estimates are highly conservative so that any actual risks are likely to be substantially less. This is because, for example, while the maximum concentration observed among composite samples (with contributions from any embedded ACM included) were employed (Table 16, Row 4) to estimate these risks, ATV-riding tends to be conducted over large areas that are not well represented by the single maximum concentration used here to assess exposure and risk[25]. Moreover, the concentration estimated for these pathways include contributions from the embedded ACM, which will not be fully realized until some time in the distant future when this material completely degrades and releases all of its fibers to the surrounding soil. Perhaps even more important, as with the models for walking, running, or bicycling, the model employed for ATV-riding actually predicts exposures to individuals who constantly travel immediately behind the individual who is riding so that exposures (and the attendant risks) to riders from their own plume will be substantially smaller (see Section 5.3.1).

Given all of the above considerations, it is likely that any actual chrysotile-related risks to residents who ride ATV's at the North Ridge Estates Site will remain within the range considered acceptable by U.S.EPA on a site-specific basis. Depending on need, a more sophisticated analysis of this pathway may be incorporated into the final risk assessment for the North Ridge Estates Site.

5.5.1.2 Assessing risk attendant to construction-related activities

The lower half of Table 19 presents chrysotile-related exposure and risk estimates associated with two hypothetical, future construction scenarios. The first involves a future project that would last a year and would include excavation and disturbance of a substantial amount of soil (such as might be required to construct additional housing on site). Estimates of exposure and risk potentially experienced by workers during such a project are presented in the rows in the table under the heading, "Worker Pathways." The exposure and risk potentially experienced by residents should such a project be undertaken are presented in the first and second rows under the heading, "Offsite Impact to Residents." Note that the exposure (and the attendant risk estimates) for workers were calculated assuming no dust control and, separately, assuming implementation of dust control required to control nuisance dust.

Based on the results presented in Table 19, as long as workers perform the kinds of dust control activities that are routinely required to control nuisance dust in association with commercial excavation and construction (OSHA 1987), risks to workers fall within the middle of the range potentially considered acceptable by U.S.EPA when site-

25 As indicated in Appendix F, these concentrations are also found to adequately bound the sampling conducted by U.S.EPA on individual, residential lots that was designed to provide conservatively-biased, worst-case source concentration estimates for those lots.

specific considerations are addressed. At the same time, the results presented in the table also suggest that conducting such activities without adequate dust control might subject workers to elevated risks posed by exposure to chrysotile, although a more sophisticated analysis would be needed to confirm this.

Regarding residents, the exposure and risk estimates presented in the first row under the heading “Offsite Impact to Residents” at the bottom of the table were calculated assuming a complete lack of controlling for dust. Thus, it appears that, whether workers control for dust or not, risks posed to local residents as a consequence of future construction activities at the North Ridge Estates site fall in the lower end of the range of potentially acceptable risks[26].

The second construction scenario presented in Table 19 involves hypothetical remediation of chrysotile-containing burial piles or other hot spots identified on site. It was further assumed that such activities would last 2-months and would involve disturbance of material exhibiting chrysotile concentrations equivalent to maximum observed from any hot spot on site with contributions from the embedded ACM included. Estimates of exposure and risk potentially experienced by workers during such a remediation project are presented in the rows in the table under the heading, “Worker Pathways (Remediation Scenario).” The exposure and risk potentially experienced by residents should such a remediation project be undertaken are presented in the third and fourth rows under the heading, “Offsite Impact to Residents.” As with the first construction scenario, the exposure (and the attendant risk estimates) for workers were calculated assuming no dust control and, separately, assuming required dust control.

Based on the results presented in Table 19, as long as remediation workers perform the kinds of dust control activities that are routinely required to control nuisance dust in association with commercial excavation and construction (OSHA 1987), chrysotile-related risks to workers fall within the range potentially considered acceptable by U.S.EPA when site-specific considerations are addressed. At the same time, the results presented in the table also suggest that conducting such activities without adequate dust control might subject workers to elevated risks posed by exposure to chrysotile, although a more sophisticated analysis would be required to confirm this.

Regarding residents, the exposure and risk estimates presented in the third row under the heading “Offsite Impact to Residents” at the bottom of the table were calculated assuming a complete lack of controlling for dust. Thus, it appears that, whether workers control for dust or not, chrysotile-related risks posed to local residents as a consequence of future remediation activities at the North Ridge Estates site fall within the range of potentially acceptable risks[24].

---

[26] Note that the exposures and risks estimated in Table 19 for residents that are attributed to construction-related activities are the same whether dust control is considered or not. This is an artifact due to the different features incorporated into the calculations to assure that each are adequately conservative.

5.5.1.3 **Other considerations**

The chrysotile-related risk estimates listed in Table 19 are based on source concentration estimates that include the combined contributions of both the free asbestos structures observed within the soil component of the samples analyzed and the asbestos structures found within the embedded ACM component of each sample. For purposes of estimating risk, the asbestos structures observed within the ACM component of each sample was further assumed to have been entirely liberated so that they were all available for emission when disturbed.

With one exception, the data presented in Table 6 indicate that contributions from the ACM component of each sample dominates the overall contributions to total asbestos concentrations and, therefore, to risk. This is expected because all of the asbestos (including any found within the soil component of a sample) is believed to have originated in ACM. The one exception to this general observation involves the potentially anomalous pair of samples (Nos. 76 and 98), neither of which appear to represent a true, pure soil component for the matrix analyzed (see Section 4, discussion of the values in Table 1).

Given the primary importance of ACM contributions to asbestos exposure and risk, it may prove useful to establish a target mass fraction of ACM in soil above which contributions to asbestos from ACM are likely to be unacceptable (should such ACM completely degrade so that all of the asbestos within the material is liberated to the soil). A preliminary estimate for such a target mass fraction can be derived relatively simply in the manner described below.

To estimate a value for a target acceptable mass fraction of ACM, it is first necessary to identify the most critical scenario that will be used to link soil concentrations to airborne exposure and risk. This can be simply accomplished by dividing the risk estimates provided in the last two columns of Table 19 by the corresponding input source concentrations presented in Columns 3 and 4 (for protocol structures and 7402 structures, respectively). The resulting ratio can be thought of as the risk per unit of source concentration estimated for each of the exposure pathways evaluated in the Table. It is then a matter of identifying the exposure pathway that produces the greatest risk per unit of source concentration.

Considering only exposure and risk to residents, the exposure pathway that produces the greatest risk per unit of source concentration is running. Thus, $4.9x10^{-12}$ (which is determined as: $9.3x10^{-5}/1.9x10^{7}$ for protocol structures) and $1.1x10^{-11}$ (which is determined as $8.3x10^{-5}/7.2x10^{6}$ for 7402 structures) are the largest risks per unit of source concentration estimated for any of the pathways involving residential exposure that are listed in Table 19.

To derive a preliminary estimate for a target acceptable concentration of ACM in soils, it is first necessary to estimate the maximum total concentration of asbestos that is acceptable in soils. This is accomplished using the most critical exposure pathways (running) by dividing a target acceptable level of risk by the risk per unit of source concentration derived for running as described above. The target acceptable risk level chosen here is $1x10^{-4}$, which is the upper end of the risk range potentially considered acceptable by U.S.EPA when site-specific considerations are addressed. Thus, for protocol structures, the target acceptable total concentration of asbestos in soils is $2.0x10^{7}$ ($1x10^{-4}/4.9x10^{-12}$). Similarly, for 7402 structures, the value is $9.1x10^{6}$ ($1x10^{-4}/1.1x10^{-11}$).

To complete the derivation for a target acceptable concentration of ACM in soils, it is simply necessary to divide the target acceptable maximum concentration of asbestos in soils (derived as described above) by the maximum concentration of asbestos observed in ACM at the site. Thus, for chrysotile as protocol structures, the target acceptable mass fraction of ACM in soils is 0.3% ($2.0x10^{7}/6.3x10^{9}$), noting that the maximum concentration of chrysotile protocol structures observed in ACM is reported on line 6 of Table 16. Similarly, for chrysotile as 7402 structures, the target acceptable mass fraction of ACM in soils is 0.4% ($9.1x10^{6}/2.2x10^{9}$). Thus, as long as the mass fraction of ACM in soil remains below 0.3%, the ACM component of that soil would not contain a sufficient quantity of chrysotile asbestos to create a risk exceeding $1x10^{-4}$ to residents at the North Ridge Estates Site, even if such ACM were to completely degrade and liberate all of the asbestos contained within.

Note that a target acceptable mass fraction for ACM in soils, such as that described above, can potentially be used to provide a quantitative discriminator for defining hot spots at the North Ridge Estates Site.

5.5.2 Assessing amphibole-related risks

Activity-specific exposures and the attendant risks estimated for amphibole asbestos are summarized in Table 20. The layout for Table 20 is identical to that described for Table 19.

Amphibole concentrations determined in soils (source materials) at the site that are appropriate for each of the exposure pathways of interest are presented in the third and fourth columns of Table 20 for protocol structures and 7402 structures, respectively. These are reproduced either from Table F-2 (of Appendix F) or Table 16 and selected as described in Section 5.3.4.2. Each of the estimated source concentrations represent conservative, upper bounds for the conditions represented, given the adequacy of the existing data set, which is addressed explicitly in Section 5.3.4.2 and described briefly for each pathway below. Exposure point concentrations for amphibole asbestos are presented in the fifth and sixth columns of Table 20, for protocol structures and 7402 structures, respectively, and the corresponding risk estimates are listed in the last two columns of the table.

In Table 20, risks that are estimated to exceed $1x10^{-4}$ (one in ten thousand) are highlighted. These estimates exceed the upper end of the risk range (10^{-6} to 10^{-4}) that is potentially considered acceptable by U.S.EPA when site-specific conditions are addressed. However, as previously indicated, this does not automatically indicate that the actual risks associated with any particular pathway should be considered unacceptable. The implications of the risk estimates presented in these tables are addressed below for each of the exposure pathways listed in the risk tables.

Importantly, as previously indicated, this report is intended as a preliminary risk assessment so that a relatively simple, extremely conservative, bounding analysis was conducted to assess risk. Therefore, while it is proper to conclude from these estimates that risks are acceptable, a more sophisticated evaluation would need to be conducted before any risks that are *estimated* to be unacceptable are reasonably *concluded* to be unacceptable. The uncertainties associated with the existing data, which were highlighted in Section 5.3.4.2 and are considered further in the general discussion of uncertainty (Section 5.6), are also addressed in the following assessment of risks.

Risks associated with residential exposure pathways and worker exposure pathways are separately addressed below.

5.5.2.1 Assessing risk associated with activities by local residents

As can be seen in Table 20, none of the amphibole-related risks estimated for residential pathways involving walking, running, bicycling, rototilling, gardening, or children playing in dirt exceed the upper end of the risk range potentially considered acceptable by U.S.EPA when risks are estimated based on either protocol structure concentrations or 7402 structure concentrations. In contrast, the risk estimated for ATV riding slightly exceeds the upper end of this range and the risk estimated for abrading ACM exceeds the upper end of the range by a substantial margin. Risks from each of these pathways are addressed in greater detail below.

Walking, Running, and Bicycling

The amphibole-related risks estimated for walking, running, and bicycling in Table 20, assume that such activities will be conducted over large areas of the site that are represented by upper bound estimates of averaged conditions (see Section 5.3.4), derived within the uncertainty of the existing data set, as described in Section 5.3.4.2. Even given the uncertainty of the available data, these estimates are expected to provide adequately conservative estimates of source concentrations for these pathways, especially given that they are based on an upper bound estimate for the concentrations of amphibole asbestos structures that were not even detected within the U.S.EPA dataset that, in turn, was intended to provide bounding estimates for conditions on individual residential properties (Appendix F).

As previously indicated, the exposure and risk estimates for these pathways are also expected to be highly conservative due to the manner in which they were modeled (Section 5.3.1) coupled with the use of multiple, conservative estimates of the values for the input parameters required for each model (Section 5.3.2). This is particularly true for walking, running, and bicycling where the model employed actually predicts exposures to hypothetical individuals who would constantly travel immediately behind the individual who is walking, running, or bicycling so that exposures (and the attendant risks) to walkers, runners, or bicyclists from their own plume would be substantially smaller (see Section 5.3.1).

Despite the degree to which the risk estimates for these pathways represent conservative upper bounds, the risks presented in Table 20 fall within the risk range potentially considered to be acceptable by U.S.EPA. Thus, risks posed to residents during walking, running, or bicycling across neighborhood soils fall within the range potentially considered acceptable by U.S.EPA on a site-specific basis.

For running, walking, bicycling, or other pathways for which exposure is derived over relatively large areas, it appears likely that the existing data set is conservative, although not as conservative as for chrysotile (Section 5.3.4.2). Certainly, the existing data do not suggest a problem.

Gardening and Children Playing in Soils

The risks estimated for gardening and children playing in soils that are presented in Table 20 should also be considered to be conservative because they are based on source concentrations set equal to the maximum observed concentration in hot spot soils with contributions from ACM included (the first row under the heading, “Amosite” in Table 16). Moreover, the uncertainty associated with these estimates was already addressed (Section 5.4.3.2). Thus, as long as amphibole asbestos-containing ACM is not exposed, the source concentration estimates derived as previously described for these pathways are expected to be conservative, It is also unlikely that gardeners or children playing would dig sufficiently deep to encounter the known, buried steam pipe on site (at a depth of 2 ft).

These risk estimates should also be considered conservative due to the multiple, conservative assumptions incorporated into the exposure modeling (see Section 5.3.2). Despite the degree to which the risk estimates for these pathways represent conservative upper bounds, the amphibole-related risks presented in Table 20 for gardening and children playing in dirt fall within the risk range potentially considered to be acceptable by U.S.EPA. Thus, amphibole-related risks posed to residents during gardening or children playing in local soils fall within the range potentially considered acceptable by U.S.EPA on a site-specific basis.

Given the above, it is unlikely that amphibole-related risks attendant to exposure from gardening or children playing in dirt pose unacceptable risks to local residents, although this conclusion may be further refined should additional characterization of the site be conducted to further reduce the uncertainty of the existing data and to assure that potential amphibole asbestos hot spots are identified and addressed.

Handling and Abrading ACM

As indicated in Table 20, the risk estimated for the exposure pathway involving abrasion of amphibole-containing ACM (specifically steam-pipe insulation) exceeds the upper end of the range of values potentially considered acceptable by the U.S.EPA by a substantial margin. Although, the risk estimate presented in the table for this pathway may be conservative, especially if such material is merely handled, rather than actively abraded (as previously described), prudence dictates that handling of amphibole-containing ACM should generally be minimized and intentionally abrading the material should clearly be avoided. At the same time, if a need arises to better estimate the magnitude of such risks, a more sophisticated analysis of this pathway may be incorporated into the final risk assessment for the North Ridge Estates Site.

Rototilling

The amphibole-related risks estimated for rototilling that are presented in Table 20 are within the range generally considered acceptable by U.S.EPA. This is expected to remain true, barring regular and continued rototilling in areas where steam-pipe insulation has been exposed. Any such areas appear to be limited in extent and known ones have already been removed from the site. However, given the uncertainty of the existing database used for source characterization of amphibole asbestos, additional characterization may be helpful to better bracket the risks posed by rototilling in local soils and to assure that any potential amphibole asbestos hot spots are adequately identified and addressed.

To be conservative, the amphibole-related risk estimates for rototilling are based on the assumption that the two short structures observed among the U.S.EPA samples infer the possible presence of biologically active structures representing a low, general level of amphibole contamination and upper bound estimates of the concentration of such amphibole asbestos were derived as described in Appendix F, with the uncertainties addressed in Section 5.3.4.2. Even given this assumption, the amphibole-related risks estimated for rototilling at the North Ridge Estates Site are within the range potentially considered acceptable by U.S.EPA on a site-specific basis.

ATV-riding

The amphibole-related risk estimated for ATV-riding in Table 20 slightly exceeds the upper end of the risk range that is potentially considered acceptable by U.S.EPA when site-specific conditions are addressed when risks are assessed based on protocol structures. When risks are assessed based on 7402 structures, they fall within the range potentially considered acceptable. This difference is due to the use of a URF for amphibole asbestos that assumes greater potency than for chrysotile asbestos (Berman and Crump 2001). The URF currently recommended by the U.S.EPA (IRIS 1988) for asbestos does not incorporate consideration of a difference in potency between the fiber types. This latter URF is employed for the evaluation of risk associated with exposure to 7402 structures.

Both the amphibole-related risk estimates derived for ATV-riding are highly conservative so that any actual risks are likely to be substantially less. This is because, for example, the source concentration employed to assess these risks is actually an upper bound estimate for the concentration of structures that were not even detected (Section 5.3.4.2). Perhaps even more important, as with the models for walking, running, or bicycling, the model employed for ATV-riding actually predicts exposures to individuals who constantly travel immediately behind the individual who is riding so that exposures (and the attendant risks) to riders from their own plume will be substantially smaller (see Section 5.3.1).

Given all of the above considerations (including the consideration, previously discussed concerning the adequacy of the existing database, see discussion under Walking, Running, Bicycling above), it is likely that any actual amphibole-related risks to residents who ride ATV's at the North Ridge Estates Site will remain within the range considered acceptable by U.S.EPA on a site-specific basis. To confirm this, a more sophisticated analysis of this pathway potentially supplemented with limited, additional characterization may be incorporated into the final risk assessment for the North Ridge Estates Site.

5.5.2.2 Assessing risk attendant to construction-related activities

The lower half of Table 20 presents amphibole-related exposure and risk estimates associated with two hypothetical, future construction scenarios. The first involves a future project that would last a year and would include excavation and disturbance of a substantial amount of soil (such as might be required to construct additional housing on site). Estimates of exposure and risk potentially experienced by workers during such a project are presented in the rows in the table under the heading, "Worker Pathways." The exposure and risk potentially experienced by residents should such a project be undertaken are presented in the first and second rows under the heading, "Offsite Impact to Residents." Note that the exposure (and the attendant risk estimates) for workers were calculated assuming no dust control and, separately, assuming use of dust mitigation that is required to control for nuisance dust.

Based on the results presented in Table 20, as long as workers perform the kinds of dust control activities that are routinely required to control nuisance dust in association with commercial excavation and construction (OSHA 1987), risks to workers fall within the range potentially considered acceptable by U.S.EPA when site-specific considerations are addressed. At the same time, the results presented in the table also suggest that conducting such activities without adequate dust control might subject workers to elevated risks posed by exposure to amphibole asbestos, although a more sophisticated analysis should be considered to confirm this.

Regarding residents, the exposure and risk estimates presented in the first row under the heading "Offsite Impact to Residents" at the bottom of the table were calculated assuming a complete lack of controlling for dust. Thus, it appears that, whether workers control for dust or not, risks posed to local residents as a consequence of future construction activities at the North Ridge Estates site fall in the lower end of the range of potentially acceptable risks[27].

The second construction scenario presented in Table 20 involves hypothetical remediation of chrysotile-containing burial piles or other hot spots identified on site. It was assumed that such activities would last 2-months and would involve disturbance of material exhibiting the levels of amphibole-asbestos contamination observed in the single hot-spot sample (No. 6) in which amphibole asbestos was detected.

Estimates of amphibole-related exposure and risk potentially experienced by workers during such a remediation project are presented in the rows in the table under the heading, "Worker Pathways (Remediation Scenario)." The exposure and risk potentially experienced by residents should such a remediation project be undertaken are presented in the third and fourth rows under the heading, "Offsite Impact to Residents." As with the first construction scenario, the exposure (and the attendant risk estimates) for workers were calculated assuming no dust control and, separately, assuming required dust control.

Based on the results presented in Table 20, if remediation workers perform the kinds of dust control activities that are routinely required to control nuisance dust in association with commercial excavation and construction (OSHA 1987), risks to workers will slightly exceed the range potentially considered acceptable by U.S.EPA when site-specific considerations are addressed. Thus, coupled with the risks estimated for the abrading of amphibole-containing ACM, workers who might conduct future remediation activities at the site in areas where amphibole asbestos exists may want to consider appropriate respiratory protection. Alternatively, the need for such protection may be reconsidered following completion of a more sophisticated analysis of this pathway.

Regarding residents, the exposure and risk estimates presented in the third row under the heading "Offsite Impact to Residents" at the bottom of the table were calculated assuming a complete lack of controlling for dust. Thus, it appears that, whether workers control for dust or not, risks posed to local residents as a consequence of future remediation activities at the North Ridge Estates site fall within the range of potentially acceptable risks.

5.5.3 Assessing impacts from combined chrysotile and amphibole-related risks

As previously indicated, due to the use of conservative, upper bound estimates of risk, it is not strictly appropriate to add the contributions to risk derived, respectively, for exposure to chrysotile and amphibole asbestos[28]. Moreover, changes in risk estimates

---

[27] Note that the fact that the same risk estimates are indicated for residences in this table, whether dust control is considered or not is an artifact of the manner in which the calculations were conducted (see the previous footnote on this topic in Section 5.5.1.2).

[28] Note that questions concerning the summing of risks across exposure pathways was explicitly addressed in Section 5.3.3.

resulting from summing across these risks can be no greater than a factor of two, which is a very small adjustment relative to other considerations concerning the degree to which risk estimates are conservative. Nevertheless, to simplify discussion of such effects, results from summing such risk estimates are provided in Table 21.

As with Tables 19 and 20, the first column of Table 21 lists the specific exposure pathways of interest. Risks attendant to chrysotile exposure, based on evaluation of protocol structures or 7402 structures are summarized in the second and third column of Table 21, respectively. Corresponding risks attributable to amphibole asbestos are presented in Columns 4 and 5 of Table 21 and the combined risks attendant to total asbestos are presented in the last two columns of the table.

Comparing across the columns of Table 21, it is apparent that only three additional entries are highlighted in the last two columns of the table that have not been previously highlighted in at least one of the first four columns of the table. Thus, there are only three cases where the summing of risks creates a combined risk estimate that exceeds the upper end of the range of risks potentially considered acceptable when neither chrysotile- nor amphibole-related risks alone suggest a possible exceedence.

The three highlighted risk estimates in Table 21 that are uniquely attributable to adding chrysotile and amphibole risks are for running, bicycling, and combined child's play/gardening (and only when risks are estimated based on protocol structures). These three risk estimates slightly exceed the upper end of the range potentially considered acceptable by U.S.EPA when site-specific conditions are addressed. However, given the degree to which the component estimates (for chrysotile- and amphibole-related risks) that go into these combined estimates are believed to be conservative (as described in Sections 5.5.1.1 and 5.5.2.1), it is unlikely that any actual risks associated with walking, bicycling, or combined child's play/gardening at the North Ridge Estates Site would exceed the upper end of the risk range. Therefore, if there is a need to better account for combined risks, these pathways may be subjected to a more sophisticated evaluation in the final risk assessment for the North Ridge Estates Site.

Regarding all of the other exposure pathways that are addressed in Table 21, the detailed considerations concerning the degree to which such estimates may be considered to be conservative are provided in Sections 5.5.1 and 5.5.2.

5.5.4 Considering the need for immediate removals

With the exception of the risks estimated for the intentional abrading of amphibole asbestos-containing ACM, none of the other risk estimates presented in Tables 19, 20, or 21 exceed the upper end of the risk range potentially considered acceptable by U.S.EPA when site specific conditions are addressed. Thus, none of these other risks, which are all extremely conservative estimates, suggest the need for any kind of immediate action. In fact, especially if the few risk estimates that slightly exceed the risk range are reassessed using more sophisticated procedures, it would likely indicate that none of these risks exceed levels that are potentially considered acceptable for permanent conditions.

In contrast, the risks estimated for the intentional abrading of amphibole asbestos-containing ACM (e.g. steam-pipe insulation) suggests that whenever this material is observed on the site, it should be removed or encapsulated so as to minimize the opportunity for contact by local residents. In concurrence with this conclusion, to date, all known exposed areas of this material have been addressed.

Given the above, with the exception of any areas where amphibole asbestos-containing ACM should become exposed in the future, taking the time necessary to complete an assessment of the site that is adequate for supporting identification, design, and implementation of a final, permanent remedy will not pose an unacceptable risk to residents of the North Ridge Estates Site.

5.6 Considering Uncertainty

When drawing conclusions from a risk assessment, it is critical that the sources and handling of uncertainty be adequately considered. Typically numerous and varied sources of uncertainty contribute to a risk assessment so that the overall uncertainty of the resulting risk estimates can be substantial. Therefore, it is general practice to *control* for such uncertainty by incorporating conservative biases into the estimation of risk so that the resulting risk estimates are highly likely to be greater than any actual risks. At the same time, such biases must be introduced with prudence or the value of using the results of the risk assessment to support risk management decisions can be compromised.

When controlling for uncertainty through the intentional incorporation of conservative biases, it is important to consider both the relative magnitudes of the contributions to uncertainty from specific sources and, more importantly, the impact of introducing multiple, independent factors, whose combined effects are multiplicative. Combining more than a very small number of these factors in a risk assessment can very quickly increase the magnitude of the bias to the point where the utility of the estimate becomes questionable. At best, such an estimate serves only to support conclusions concerning the lack of an unacceptable risk. It is useless for suggesting the presence of an unacceptable risk.

The likely primary sources (and relative magnitudes) of uncertainty in the risk estimates developed in this study are summarized in Table 22. Sources of variability[29] vs. uncertainty[30] are also distinguished in the table. This is important because, in some

---

[29] Variability is a measure of the degree to which an actual distribution of measurable quantities differs from one location to the next. For example, the concentrations of asbestos in site soils vary from one location to the next.

[30] Uncertainty is a measure of the lack of knowledge about a particular measured or estimated quantity. For example, when measuring the concentration of a particular sample, given the finite

cases, variability may be handled differently from uncertainty when managing risk. For example, exposure and risk may vary as a function of the behavior of exposed individuals and there is general interest in protecting even those who may otherwise be at increased risk due to their own behavior (as long as their behavior is not so extreme as to be outside the norm). In contrast, it is general practice to control for overall uncertainty (i.e. for all component sources of uncertainty combined) by being sure that the chance of being wrong about a decision is less than some pre-defined maximum probability (error rate). Moreover, when warranted, uncertainty can be reduced through further characterization. In contrast, the effects of variability do not change with increased characterization.

In Table 22, the first column lists each of the primary sources of uncertainty or variability. The second column indicates whether it is uncertainty or variability that is being considered. The third column indicates a qualitative indication of the relative magnitude of the "error" (which means "uncertainty") potentially contributed by each particular source to final estimates of risk. The last column of the table indicates how each of the various sources of uncertainty or variability is addressed in this risk assessment.

As is apparent from Table 22, with the exception of a few of the smaller sources, all of the primary sources of uncertainty and the contributions to variability are addressed by incorporating conservative assumptions or adjustments. Thus, the risk estimates derived in this study (with the possible exception of the estimates associated with abrading ACM and the amphibole-related risk estimates potentially affected by the uncertainty of the existing database, as addressed below) should be considered to be extremely conservative, upper bounds.

As previously indicated, although there is substantial uncertainty in the models adapted to evaluate several of the exposure pathways addressed in this report, due to the use of multiple, conservative assumptions; it can be stated with confidence that the risk estimates derived are indeed conservative upper bounds. To provide an indication of the degree to which some of the risk estimates in Tables19, 20, and 21 (specifically the risk estimates for running, walking, and bicycling)[31] are conservative, consider that:

- the maximum concentrations observed among measurements collected in the appropriate bulk matrices were employed in the calculations;

---

precision of the measurement, the true concentration can only be determined to within some range around the measured concentration.

[31] Note that the above discussion summarizes details of multiple discussions previously presented in this document to highlight the degree of conservatism incorporated in the manner in which models were adapted and applied (Section 5.3.1), in which values were selected for input parameters (Section 5.3.2), and in which source concentrations were chosen to represent each exposure pathway of interest (Section 5.5). Similar considerations are also addressed in these sections for each of the other exposure pathways evaluated in this document.

- contributions from the ACM found within the soil matrix were included based on the extremely conservative assumption that the ACM would completely degrade and release 100% of its asbestos content to the surrounding soils;

- conservative (low) estimates for moisture content and conservative values for most other input parameters were employed in the modeling;

- conservative dispersion estimates were employed in the modeling. In fact, specifically for running, walking, and bicycling the fact that a participant in these activities would constantly move out ahead of their own plume was entirely ignored. Due to such movement, participants would receive at most only intermittent, minimal exposure from their own dust cloud. Rather, the models were run in a manner simulating exposure to individuals who remain immediately behind a lead individual participating in the same activity. Yet, it is highly unlikely that individuals conducting such activities would be positioned relative to others so as to remain precisely "downwind" for any but a very small fraction of the total time that they participate in any of these activities; and

- conservative estimates of both the frequencies and durations of such activities were employed in the modeling.

As previously indicated, use of multiple, conservative input assumptions in risk calculations in this manner typically results in extremely conservative estimates of risk. The proper way to address use of multiple, conservative input assumptions (to provide more realistic but still health protective estimates of risk) is to conduct a Monte Carlo type analysis and this is under consideration for the final, integrated risk assessment that will be produced for this site.

Importantly, calculations such as those illustrated above need to be viewed with caution because they require that all other factors contributing to uncertainty at least be more likely than not to be conservative. One factor in this preliminary risk assessment that may somewhat mitigate the degree to which risk estimates are conservative involves the degree to which the sampling scheme employed to characterize the site in support of this risk assessment is adequately matched to the size of the source areas that contribute to the majority of exposure via each of the exposure pathways of interest.

For the most part, the adequacy of the sampling scheme was addressed through use of the positively biased sampling that was performed. Thus, as indicated in Section 5.3.4, it is apparent that source concentrations used to model exposure and risk are adequately conservative to address chrysotile-related risks for all of the pathways evaluated. For gardening, playing in dirt, and the remediation-related construction scenario, the maximum concentration of asbestos observed anywhere (including hot spots) with the full contribution from the embedded ACM included was employed as the estimated source concentration. For walking, running, bicycling, rototilling, and ATV riding, the maximum composite concentration with the full contribution from the embedded ACM included was employed as the estimated source concentration and this was also shown to be conservative for the worst-case soil sampling of residential properties that was conducted by the U.S.EPA (Appendix F). Moreover, these latter activities tend to be conducted over relatively large areas with relatively less time spent within the boundaries of a single residence than the previously listed activities.

The same maximum concentration among composite samples with contributions from ACM included was also employed for the commercial construction scenario. Given that this scenario is assumed to last a year, the dust from soil generating activities from a reasonably large number of houses would be included within this time estimate. Thus, it is appropriate to employ a source concentration that represents an upper bound estimate over a large area. If shorter duration projects are conducted (such as construction of a single house), this could only result in smaller overall exposure because the exposure contributions from the rest of the year, which would derive from the portion of the "averaged area" that is not affected by the project, would then be zero.

The extreme source concentration employed for evaluating the intentional abrading of ACM is also clearly conservative.

As indicated in Section 5.5.2.1, however, due to the greater potency assumed for amphibole asbestos relative to chrysotile (Section 5.4), areas of the site exhibiting lower concentrations of amphibole asbestos or areas exhibiting higher concentrations but less frequently encountered than those containing chrysotile could potentially have a greater impact on overall exposure and risk. Therefore, for some of the exposure pathways evaluated in this study, the existing site model and database may need to be supplemented before it is possible to conclude with adequate confidence that amphibole-related risks are adequately bounded.

Given the above, source concentration estimates for amphibole asbestos employed in this study are likely conservative for any exposure pathways that occur over relatively larger areas (including, walking, running, bicycling, rototilling, ATV-riding, and commercial construction). The higher source concentration estimate employed to assess the remediation scenario is also likely conservative and is also conservative for gardening and playing in dirt, as long as such activities are not conducted in areas where the concentration of steam-pipe insulation exceeds approximately 0.03% of the mass of the soil in which it is embedded[32]. This value may also be adjusted, if needed, by conducting a more sophisticated evaluation of these pathways in support of the final risk assessment for the site.

To confirm that ACM remains below target concentrations in surface materials, it will be necessary to consider contributions from ACM that may potentially reach the surface and degrade. ACM has appeared in some areas from which surface ACM was previously removed (potentially due to any of several mechanisms including freeze-thaw cycling, water-driven erosion, transport by borrowing animals, lack of prior observation

[32] Note that the value of 0.03% defined for a mass concentration limit to steam-pipe insulation in soils was estimated in a manner similar to that described previously for establishing a target acceptable mass concentration of ACM in soils for chrysotile (Section 5.5.1.3).

due to obscuring foliage, etc.). Therefore, depending on how the risks associated with the resurfacing of material are to be addressed, it may be prudent to conduct limited additional field characterization suitable for determining the vertical profile of the ACM contamination that is present.

The source concentration assumed for abrading of amphibole-containing ACM is also expected to be conservative.

The least certain of the risk estimates presented in Tables 19, 20, and 21 are those associated with the intentional abrading of ACM. Although it is expected to be generally conservative, lack of knowledge concerning the degree of uncertainty associated with several of the specific input values used for the modeling to derive these risk estimates makes it difficult to judge the degree to which the overall risk estimates are conservative for this pathway. Additional evaluation of this pathway is thus being considered

6. CONCLUSIONS AND RECOMMENDATION

As previously indicated, this report presents a preliminary risk assessment that is intended to:

- assess the need for immediate (versus long-term) action to protect public health at the North Ridge Estates Site;
- identify and focus issues most relevant to assessment of risk at the site; and
- identify data gaps and focus further study at the site that will be suitable for supporting final decisions concerning a permanent remedy.

A summary of conclusions and recommendations for the three objectives of this report are each addressed separately below.

6.1 Assessing the Need for Immediate (Versus Long-Term) Action

With one exception, the results of the risk assessment presented in this report indicate that risks posed by the presence of asbestos at the North Ridge Estates Site are sufficiently low so that immediate actions to reduce them are not warranted. Thus, taking the time required to complete site characterization and an assessment of risks that are adequate for supporting the required risk-management decisions for the site will not pose an unacceptable risk. It is therefore recommended that such investigation and analysis be completed in a timely manner so that decisions concerning a permanent remedy for the site can be based on sound technical information.

The one exception involves the need to limit opportunities for exposure to amphibole asbestos-containing ACM. Any steam-pipe insulation that is exposed at the surface of the site should be encapsulated or removed.

6.2 Identifying and Focusing Issues

The discussion of issues is divided into general conclusions and recommendations.

The relevant conclusions of this study can be summarized as follows:

- the vast majority of asbestos observed at the North Ridge Estates Site is chrysotile. Although it is known that amosite (an amphibole asbestos) is associated with the steam-pipe insulation that exists at the site and debris containing such insulation was observed in three small, isolated areas of the site (which have been cleaned up), amosite asbestos structures were observed only rarely in samples collected and analyzed at the site;

- for residents who might walk, run, bicycle, rototill, or ride ATV's at the site, such activities are unlikely to present unacceptable risks, as long as the opportunity for exposure to amphibole asbestos-containing soils or ACM (e.g. steam-pipe insulation) remains limited. For some of these pathways (including ATV riding in particular), completion of a more sophisticated (less extreme) assessment would provide an improved indication of the upper limits to risk posed by asbestos exposure associated with this pathway;

- children who play and residents who garden in site soils (even in hot spot areas where the highest concentrations of ACM were observed) are unlikely to be exposed to asbestos at levels posing an unacceptable risk, as long as the opportunity for exposure to amphibole asbestos-containing soils or ACM (e.g. steam-pipe insulation) remains limited;

- in general, for areas in which the concentrations of asbestos in the soils themselves are low, removing visible chrysotile-containing ACM (so that the mass fraction of any remaining ACM is below 0.3%[33]) should render soils generally suitable for the kinds of common activities considered above. Even if the remaining ACM were to completely degrade, the resulting asbestos concentrations in the soils would not be adequate to pose an unacceptable risk;

- the handling of pieces of chrysotile-containing ACM (as long as they are not intentionally abraded by cutting, sanding, or scraping) should not pose an undue concern even though risk estimates attendant to this exposure pathway are the least certain of all of the exposure pathways evaluated. At the same time, it appears that activities causing chrysotile-containing ACM to be intentionally abraded should generally be avoided;

33 This value represents the actual mass or weight percent of ACM in soil (as might be determined, for example, by gravimetric analysis). Such values should NOT be confused with measurements of area % of asbestos structures that are typically determined by PLM. Neither should they be confused with the concentration of asbestos in the ACM itself.

- the intentional abrading of amphibole asbestos-containing ACM (by cutting, sanding, or scraping) should be avoided and even occasional handling of amphibole asbestos-containing ACM should be minimized;

- future construction conducted at the site should not pose an unacceptable risk to local residents, even if required measures to control nuisance dust are ignored. This remains true even if such construction were to be conducted in hot spot areas containing the highest observed asbestos concentrations (as might occur, for example, if such hot spots were to be remediated);

- future construction conducted at the site should not pose an unacceptable risk to workers as long as they practice the measures required to control nuisance dust and as long as the extent of amphibole asbestos contamination remains limited; and

- although completion of a more sophisticated (less extreme) assessment would provide an improved indication of the upper limits to risk posed by asbestos exposure during construction in areas where amphibole asbestos may be encountered at the site, use of appropriate respiratory protection should be considered for workers who disturb ACM containing amphibole asbestos for any extended period of time.

Given the results of this study, the following is recommended:

- if there is a need to reduce the uncertainty bounds for the risk estimates provided in this study for pathways in which moisture content affects dust generation, a small number of moisture content measurements could be collected in surface soils and shallow subsurface soils (spaced out over varying conditions of the year) to improve the precision of the moisture content estimates employed in the exposure modeling;

- to the degree that an improved estimate of the bounds for risks posed to residents at the North Ridge Estates Site would provide improved support for decision making at the site, it is recommended that a more sophisticated analysis of the most critical exposure pathways be completed. Depending on circumstances, risk estimates may be improved by any one or a combination of the following:

    - collecting additional measurements to develop and employ an improved estimate of the input source concentration of asbestos appropriate for each pathway of interest (see additional discussion of data gaps below);

    - collecting additional measurements at the site or in the laboratory to provide improved estimates of the input values of other model parameters that affect the estimation of exposure and risk;

    - developing or adapting more sophisticated models that better represent the actual exposures of interest (rather than representing exposures that are known to be greater than the actual exposures of interest); and/or

    - conducting sensitivity analyses and/or Monte Carlo analyses to better gauge the relative importance of the various factors affecting exposure and to derive more quantitative upper bound estimates of risk.

- due to the particular hazard posed by the presence of amphibole asbestos-containing ACM (e.g. steam-pipe insulation), it is recommended that sufficient observations and measurements be collected to adequately identify the locations of such materials at the site and actions be implemented to assure that exposure to such materials are adequately minimized. Thus, for example, a plan should be implemented to address all exposed ends and/or detached segments of steam-pipe lines at the site;

- to assure that soils remain acceptable for unrestricted use, in areas where asbestos concentrations are low in the soils themselves, it will be necessary to either to further refine risk calculations and devise an improved target or to remove chrysotile-containing ACM from soils that might be contacted so that the mass fraction of such material is reduced below 0.3% by weight. Also, a procedure needs to be devised for determining whether the residual concentration of ACM that remains in surface soils following the recent removal action (or any future removal actions) in fact achieves whatever target residual level is ultimately established; and

- other soils or bulk media containing ACM at the site should also be stabilized and isolated or remediated so as to minimize human contact to the asbestos contained within.

6.3 Identifying Data Gaps to Focus Further Study

The identification of data gaps to focus further study is divided into general conclusions and recommendations.

The relevant conclusions of this study can be summarized as follows:

- the existing data used to support this study appear adequate for supporting a conservative, bounding analysis of chrysotile exposure and risk at the site. However, additional sampling and analysis may be required, if there is a need to conduct a more sophisticated assessment of risks to better address outstanding issues regarding risk levels estimated for the specific exposure pathways evaluated in this study; and

- due to the greater potency assumed for amphibole asbestos relative to chrysotile, to support a final remedy based on the exposure pathways evaluated, it may be necessary to further bound the low concentrations of amphibole asbestos that were detected and further refine the site model to assure that potential amphibole asbestos hot spots are adequately identified and addressed.

Given the above, recommendations for addressing potential data gaps are summarized as follows:

- due to the substantial uncertainty associated with several input parameters to the model involving intentional abrading of ACM (unless additional data become available from EPA), a small, bench-scale simulation is recommended to better characterize the risks associated with this pathway;

- for areas of the site where additional information is needed to better inform risk-management decisions (i.e. to determine the need for, identify, and select among options for a permanent remedy), it is recommended that additional, focused sampling and analysis be conducted to better define the areal and vertical distribution of ACM at the site to (for example):

    - better characterize the rate at which ACM may continue to surface due to uplift from freeze-thaw cycling, erosion from water flow, or transport due to the activities of burrowing animals; and

    - better support more sophisticated analyses of specific exposure pathways to refine exposure and risk estimates.

7. REFERENCES

Baris, Y.I., Simonato, L., Artvinli, M., Pooley, F., Saracci, R., Skidmore, J., Wagner, C., "Epidemiological and Environmental Evidence of the Health Effects of Exposure to Erionite Fibres: A Four-Year Study in the Cappadocian Region of Turkey." *International Journal of Cancer,* Vol. 39, pp. 10-17. 1987.

Berman, D.W. *Preliminary Air Sampling Results for the North Ridge Estates Site, Klamath Falls (Week 3).* Submitted for U.S.EPA review and approval, October 20, 2003a.

Berman, D.W. *Sampling and Analysis Plan for a Fast-Track Sampling Program at the North Ridge Estates Site, Klamath Falls, Oregon.* Approved by U.S.EPA, August, 2003b.

Berman, D.W. *Work Plan for Conducting a Streamlined Assessment of Exposures and the Attendant Risks Posed by the Presence of Asbestos in Soils and Fill at the North Ridge Estates Site, Klamath Falls, Oregon.* Submitted to U.S.EPA for review and approval, October 14, 2003c.

Berman, D.W. "Asbestos Measurement in Soils and Bulk Materials: Sensitivity, Precision, and Interpretation -- You *Can* Have It All." in *Advances in Environmental*

Measurement Methods for Asbestos, ASTM STP 1342, M.E. Beard, H.L. Rook, Eds., American Society for Testing and Materials. Pp. 70-89, 2000.

Berman, D.W. *The Search for a Method Suitable for Supporting Risk Assessment: The Determination of Asbestos in Soils and Bulk Materials, A Feasibility Study.* USEPA publication, 1990. Under EPA review.

Berman, D.W. and Chatfield, E.J*. Interim Superfund Method for the Determination of Asbestos in Ambient Environments, Part 2: Technical Background Document*. USEPA publication: 540/2-90/005b, May 1990.

Berman, D.W. and Crump, K.S. *Technical Support Document for a Protocol to Assess Asbestos-Related Risk*. Prepared for Mark Raney, Volpe Center, U.S. Department of Transportation, 55 Broadway, Kendall Square, Cambridge, MA 02142. 2001. Under EPA Review.

Berman, D.W. and Kolk, A.J. *Draft: Modified Elutriator Method for the Determination of Asbestos in Soils and Bulk Materials, Revision 1.* Submitted to the U.S. Environmental Protection Agency, Region 8, May 23, 2000.

Berman, D.W. and Kolk, A.J. *Superfund Method for the Determination of Asbestos in Soils and Bulk Materials*. Prepared for the Office of Solid Waste and Emergency Response, U.S. Environmental Protection Agency. EPA 540-R-97-028. 1997.

Box, GEP; Hunter, WG; and Hunter, JS. *Statistics for Experimenters. An Introduction to Design, Data Analysis, and Model Building.* John Wiley and Sons. New York. 1978.

Cowherd, C; Axtell, K; Guenther, CM; and Jutze, GA. *Development of Emissions Factors for Fugitive Dust Sources.* EPA 450/3-74-085. 1974.

Cowherd, C. Jr.; Muleski, GE; Englehart, P; Gillette, DA; *Rapid Assessment of Exposure to Particulate Emissions from Surface Contamination Sites*. Office of Health and Environmental Assessment; Office of Research and Development; US Environmental Protection Agency, Washington, DC 20460. EPA/600/8-85/002, 1985.

Eastern Research Group, Inc. *Report on the Peer Consultation Workshop to Discuss a Proposed Protocol to Assess Asbestos-Related Risk*. Prepared for the Office of Solid Waste and Emergency Response, U.S. Environmental Protection Agency, Washington, D.C. 20460. Final Report, May 30, 2003.

Health Effects Institute - Asbestos Research. *Asbestos in Public and Commercial Buildings: A Literature Review and Synthesis of Current Knowledge.* HEIAR, 141 Portland St., Suite 7100, Cambridge, MA. 1991.

International Agency for Research on Cancer. *Monographs on the Evaluation of Carcinogenic Risks to Man.* Vol 14. IARC, Lyon, France. 1977.

Integrated Risk Information System-IRIS. *Toxicological Review of Asbestos.* U.S. Environmental Protection Agency. http://www.epa.gov/iris/subst/0371.htm. 1988.

International Organization for Standardization. *Ambient Air-Determination of asbestos fibers - Direct-transfer transmission electron microscopy method.* ISO 10312. 1995.

Lowry, R. *Concepts and Applications of Inferential Statistics.* Vasser College. http://faculty.vassar.edu/lowry/webtext.html. 2004.

NIOSH – National Institute for Occupational Safety and Health. *Method for the determination of asbestos in air using transmission electron microscopy*. NIOSH Method 7402. NIOSH, Cincinnati, Ohio, U.S.A. 1989.

Occupational Safety and Health Administration. *Nuisance Dust Standard.* 29 CFR 1910.1000. 1987.

Perkins, RL; Harvey, BW; *Test Method: Method for the Determination of Asbestos in Bulk Building Materials.* EPA/600/R-93/116. July, 1993.

PBS Engineering and Environmental, Inc. *Field Log Book for Soil and Hot Spot Investigation of the Rock Ridge Estates Site, Klamath Falls, Oregon*. 2003.

PBS Engineering and Environmental, Inc. *Report of Surficial Removal and Burial Location Actions. North Ridge Estates, Klamath Falls, Oregon.* January, 2004.

U.S. Environmental Protection Agency. *Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites.* Solid Waste and Emergency Response. OSWER 9355.4-24. December 2002.

U.S. Environmental Protection Agency. U.S. Environmental Protection Agency, Weis Memo to Paul Peronard regarding "Amphibole Mineral Fibers in Source Materials…" Libby Site. USEPA Region 8, December 20, 2001.

U.S. Environmental Protection Agency. Sampling and Quality Assurance Project Plan Revision I for Libby, Montana Environmental Monitoring for Asbestos Baseline Monitoring for Source Area and Residential Exposure to Tremolite-Actinolite Asbestos Fibers. http://www.epa.gov/region8/superfund/libby/QAPP_Body.pdf. 2000a.

U.S. Environmental Protection Agency. *Compilation of Air Pollution Emission Factors.* AP-42. Office of Air Quality Planning and Standards, Research Triangle Park, N.C. Online. 2000b.

U.S. Environmental Protection Agency. *Exposure Factors Handbook*. EPA/600/8089/043. Office of Health and Environmental Assessment, Washington, DC.

1997.

U.S. Environmental Protection Agency. *Air/Superfund National Technical Guidance Study Series: Volume III. – Estimation of Air Emissions from Cleanup Activities at Superfund Sties, Interim Final.* Office of Air Quality Planning and Standards, Research Triangle Park, NC. USEPA-450/1-89-003. January, 1989.

U.S. Environmental Protection Agency. *Compilation of Air Pollution Emission Factors., Volume 1: Stationary, Point, and Area Sources*. AP-42, Fourth Edition. Office of Air Quality Planning and Standards, Research Triangle Park, N.C.1985.

Walton, W.H., "The Nature, Hazards, and Assessment of Occupational Exposure to Airborne Asbestos Dust: A Review." *Annals of Occupational Hygiene*, Vol 25, pp. 117-247, 1982.

Western Regional Climate Center. Website: www.wrcc.sage.dri.edu or www.ocs.orst.edu. 2004.

TABLES

TABLE 1:

SUMMARY OF ASBESTOS CONCENTRATION MEASUREMENTS IN SOIL AND ACM SAMPLES

Soil Sample Number	ACM Sample Number	Location	Fraction ACM (g/g)	Soil Analytical Sensitivity (s/g)	ACM Analytical Sensitivity (s/g)	Asbestos Structure Counts in Soil: Short Protocol (Number)	in Soil: Long Protocol (Number)	in Soil: 7402 (Number)	Total (Number)	in ACM: Short Protocol (Number)	in ACM: Long Protocol (Number)	in ACM: 7402 (Number)	Total (Number)	Asbestos Concentrations in Soil: Total Protocol (s/g_{PM10})	in Soil: Long Protocol (s/g_{PM10})	in Soil: 7402 (s/g_{PM10})	in ACM: Total Protocol (s/g_{PM10})	in ACM: Long Protocol (s/g_{PM10})	in ACM: 7402 (s/g_{PM10})	Fraction of Long Protocol in Soil (%)	Fraction of Long Protocol in ACM (%)
1		C1	0	2.0E+06		0	0	0	0					<	<	<					
5		C2	0	1.9E+06		0	0	0	0					<	<	<					
9		C3	0.00046	1.9E+06		0	0	0	0					<	<	<					
14		C4	0.00024	2.0E+06		0	0	0	0					<	<	<					
19	51	C5	0.0013	2.0E+06	6.1E+07	0	0	0	0	11	41	13	59	<	<	<	3.2E+09	2.5E+09	7.9E+08		79%
22	52	C6	0.0022	2.0E+06	6.2E+07	0	1	1	1	51	50	35	117	2.0E+06	2.0E+06	2.0E+06	6.3E+09	3.1E+09	2.2E+09	100%	50%
25	53	C7	0.0054	2.0E+06	1.7E+07	0	0	0	0	133	68	78	238	<	<	<	3.4E+09	1.2E+09	1.3E+09		34%
29	54	C8	0.0085	2.0E+06	1.2E+07	0	0	0	0	116	57	23	186	<	<	<	2.0E+09	6.6E+08	2.6E+08		33%
34		C9	0	2.0E+06		0	0	0	0					<	<	<					
39		C10	0	1.9E+06		0	0	0	0					<	<	<					
45		Bckgnd S	0	2.0E+06		0	0	0	0					<	<	<					
56	84	HS-1	0.071	2.0E+06	3.1E+07	1	0	1	2	76	57	58	153	2.0E+06	<	2.0E+06	4.1E+09	1.8E+09	1.8E+09	0%	43%
59	88 *	HS-2	0.31	2.0E+06	2.1E+06	0	4	3	6	12	13	18	35	7.9E+06	7.9E+06	5.9E+06	5.3E+07	2.7E+07	3.8E+07	100%	52%
	90 *	HS-2	0.31		3.4E+06					10	22	16	39				1.1E+08	7.5E+07	5.4E+07		69%
64	91	HS-3	0.066	1.9E+06	3.8E+07	2	1	2	3	40	43	14	85	5.7E+06	1.9E+06	3.8E+06	3.2E+09	1.6E+09	5.3E+08	33%	52%
69	95	HS-4	0.016	1.9E+06	5.6E+07	0	0	0	0	39	32	21	80	<	<	<	4.0E+09	1.8E+09	1.2E+09		45%
71	96	HS-5	0.0086	2.0E+06	4.7E+07	0	0	0	0	33	31	45	85	<	<	<	3.0E+09	1.5E+09	2.1E+09		48%
76 [a]	98	HS-6	0.15		1.9E+06																0%
	Confirmed Chrysotile			2.0E+06		1	2	2						5.9E+06	3.9E+06	3.9E+06				67%	
	Putative Chrysotile			2.0E+06		9	4	34						2.5E+07	7.8E+06	6.6E+07				31%	
	Total Chrysotile			2.0E+06		10	6	36	49					3.1E+07	1.2E+07	7.0E+07				38%	
	Amosite			2.0E+06		2	2	8	9					7.8E+06	3.9E+06	1.6E+07				50%	
	Total Asbestos			2.0E+06		12	8	44	58					3.9E+07	1.6E+07	8.6E+07				40%	
	98 *				1.9E+06					1	0	0	1				1.9E+06	<	<		0%
	100 *				1.9E+06					0	0	0	0				<	<	<		0%
81*	101	HS-7	0.021	2.3E+06	4.2E+07	22	13	4	36	45	30	19	86	8.1E+07	3.0E+07	9.2E+06	3.2E+09	1.3E+09	8.0E+08	37%	40%

NOTES: All asbestos structures observed in all samples except Sample 76 (the soil component of HS-6) are chrysotile.

[a] A subset of the asbestos structures observed in Sample 76 are amosite and these are separately listed in the table.
The majority of the putative chrysotile structures in Sample 76 do not exhibit a clear diffraction pattern suggesting that they may have been subjected to heat.
Confirmed chrysotile, putative chrysotile, and total chrysotile from Sample 76 are separately listed in the table.
Both the soil component of HS-6 (Sample 76) and the ACM component (Samples 98 and 100) appear to contain ACM so that true separation was not achieved.
Discussion of the problems in separating soil and ACM in Sample 76 is provided in the text.

* The sample pairs: (88 and 90) and (98 and 100) are duplicate splits of the ACM components from HS-2 and HS-6, respectively.

D. Wayne Berman, Aeolus, Inc.

TABLE 2:

SAMPLE CHI-SQUARE CALCULATION TO TEST FOR THE CONSISTENCY OF STRUCTURE COUNTS OBSERVED ACROSS GRID SPECIMENS (SAMPLE NO. 52)

Gird Specimen Number	Total Structures Observed	Number of Gird Openings Scanned	Normalizing Factors	Total Structures Expected	(E-O)^2/E		
A	26	1	0.200	23.40	0.289		
B	13	1	0.200	23.40	4.622		
C	30	1	0.200	23.40	1.862		
D	19	1	0.200	23.40	0.827		
E	29	1	0.200	23.40	1.340		
Totals:	**117**	**5**	**1**	**117**	**8.940**		
				df =	4		
				critical value:=	9.49		
				Conclusions:	**Counts are consistent**		
					Deposit is adequately uniform		
					D. Wayne Berman, Aeolus, Inc.		

TABLE 3:
RESULTS OF CHI-SQUARE TESTS ACROSS GRIDS OF INDIVIDUAL SOIL OR ACM SAMPLES FROM THE NORTHRIDGE ESTATES SITE

		Chi-square Statistics					Counts Consistent?		
Sample Number	**Sample Type**	**Critical Value**	**Protocol Strictires**	**7402 Structures**	**Total Structures**		**Protocol Strictires**	**7402 Structures**	**Total Structures**
51	A	9.49	2.529	13.308	4.069		Yes	No	Yes
52	A	9.49	8.356	10.000	8.940		Yes	No	Yes
53	A	9.49	9.871	5.590	8.981		No	Yes	Yes
54	A	9.49	2.873	2.466	2.550		Yes	Yes	Yes
59	S	9.49	3.509	5.334	3.961		Yes	Yes	Yes
76	S	9.49	6.583	5.635	9.030		Yes	Yes	Yes
81	S	9.49	2.399	3.332	2.836		Yes	Yes	Yes
84	A	9.49	12.226	6.310	16.118		No	Yes	No
88	A	9.49	2.889	18.515	7.389		Yes	No	Yes
90	A	9.49	6.947	6.417	9.357		Yes	Yes	Yes
91	A	9.49	50.916	28.429	53.177		No	No	No
95	A	9.49	5.437	2.714	5.200		Yes	Yes	Yes
96	A	9.49	7.500	10.200	8.412		Yes	No	Yes
101	A	9.49	6.760	4.789	6.418		Yes	Yes	Yes

Notes;

A means ACM component sample

S means soil component sample

D. Wayne Berman, Aeolus, Inc.

TABLE 4:

RESULTS OF ANALSES OF DUPLICATE PAIR ACM SAMPLES FROM THE NORTHRIDGE ESTATES SITE, KLAMATH FALLS, OREGON

		Number of Structures			Test Statistic[a]			Conclusions		
Duplicate Pairs	**Sample Numbers**	**Protocol Structures**	**7402 Structures**	**Total Structures**	**Protocol Structures**	**7402 Structures**	**Total Structures**	**Protocol Structures**	**7402 Structures**	**Total Structures**
Pair 1	88	25	18	35	0.927	0.343	0.465	similar	similar	similar
Pair 1	90	32	16	39						
Pair 2	98	1	0	1	1	UND[b]	1	similar	UND	similar
Pair 2	100	0	0	0						

[a] Critical Value: 1.96

[b] UND means the test statisitc could not be determined because it requires dividing by zero. Nevertheless, when both samples exhibit zero structures, this indicates perfect agreement.

D. Wayne Berman, Aeolus, Inc.

TABLE 5:
RESULTS OF CHI-SQUARE TESTS ACROSS SPECIFIED SETS OF SOIL OR ACM SAMPLES FROM THE NORTHRIDGE ESTATES SITE

				Chi-square Statistics				Mutually Consistent?		
	Sample	Number of		Critical	Protocol	7402	Total	Protocol	7402	Total
Sample Set	**Type**	**Samples**	**df[a]**	**Value[b]**	**Structures**	**Structures**	**Structures**	**Structures**	**Structures**	**Structures**
All Composite Soil Samples	S	10	9	16.9	9.3	9.3	9.3	Yes[c]	Yes	Yes
All Soil Samples	S	18	17	27.6	311.0	585.0	728.0	No	No	No
All Composite ACM Samples	A	4	3	7.8	127.8	66.1	125.7	No	No	No
All ACM Samples	A	13	12	21.0	349.8	179.1	444.6	No	No	No

Notes

[a] df means degrees of freedom

[b] Source: Box et al. (1978)

[c] Alhough the critical value cannot be determined for this set, the results clearly satisfy the requirements of a Poisson because there is perfect agreement among all of the resutls (i.e. all observed results are exactly zero).

D. Wayne Berman, Aeolus, Inc.

TABLE 6:

SUMMARY OF ASBESTOS CONCENTRATIONS IN SOIL AND ACM SAMPLES (SORTED BY MASS FRACTION OF ACM IN SAMPLE)

Soil Sample Number	ACM Sample Number	Location	Fraction ACM	Asbestos Concentrations in Soil: Total Protocol (s/g_{PM10})	Asbestos Concentrations in Soil: Long Protocol (s/g_{PM10})	Asbestos Concentrations in Soil: 7402 (s/g_{PM10})	Asbestos Concentrations in ACM: Total Protocol (s/g_{PM10})	Asbestos Concentrations in ACM: Long Protocol (s/g_{PM10})	Asbestos Concentrations in ACM: 7402 (s/g_{PM10})	Asbestos Concentrations in Soil that are Attributable to ACM: Total Protocol (s/g_{PM10})	Asbestos Concentrations in Soil that are Attributable to ACM: Long Protocol (s/g_{PM10})	Asbestos Concentrations in Soil that are Attributable to ACM: 7402 (s/g_{PM10})	Total Asbestos Concentrations In Soil: Total Protocol (s/g_{PM10})	Total Asbestos Concentrations In Soil: Long Protocol (s/g_{PM10})	Total Asbestos Concentrations In Soil: 7402 (s/g_{PM10})
1		C1	0	<	<	<							<	<	<
5		C2	0	<	<	<							<	<	<
34		C9	0	<	<	<							<	<	<
39		C10	0	<	<	<							<	<	<
45		Bckgnd S	0	<	<	<							<	<	<
14		C4	0.00024	<	<	<							<	<	<
9		C3	0.00046	<	<	<							<	<	<
19	51	C5	0.0013	<	<	<	3.2E+09	2.5E+09	7.9E+08	4.2E+06	3.3E+06	1.0E+06	4.2E+06	3.3E+06	1.0E+06
22	52	C6	0.0022	2.0E+06	2.0E+06	2.0E+06	6.3E+09	3.1E+09	2.2E+09	1.4E+07	6.9E+06	4.8E+06	1.4E+07	8.9E+06	6.8E+06
25	53	C7	0.0054	<	<	<	3.4E+09	1.2E+09	1.3E+09	1.9E+07	6.3E+06	7.2E+06	1.9E+07	6.3E+06	7.2E+06
29	54	C8	0.0085	<	<	<	2.0E+09	6.6E+08	2.6E+08	1.7E+07	5.6E+06	2.2E+06	1.7E+07	5.6E+06	2.2E+06
71	96	HS-5	0.0086	<	<	<	3.0E+09	1.5E+09	2.1E+09	2.6E+07	1.2E+07	1.8E+07	2.6E+07	1.2E+07	1.8E+07
69	95	HS-4	0.016	<	<	<	4.0E+09	1.8E+09	1.2E+09	6.5E+07	2.9E+07	1.9E+07	6.5E+07	2.9E+07	1.9E+07
81*	101	HS-7	0.021	8.1E+07	3.0E+07	9.2E+06	3.2E+09	1.3E+09	8.0E+08	6.5E+07	2.6E+07	1.7E+07	1.5E+08	5.6E+07	2.6E+07
64	91	HS-3	0.066	5.7E+06	1.9E+06	3.8E+06	3.2E+09	1.6E+09	5.3E+08	2.1E+08	1.1E+08	3.5E+07	2.1E+08	1.1E+08	3.9E+07
56	84	HS-1	0.071	2.0E+06	<	2.0E+06	4.1E+09	1.8E+09	1.8E+09	2.9E+08	1.2E+08	1.3E+08	2.9E+08	1.2E+08	1.3E+08
76 [a]	98,100 [b]	HS-6	0.15	3.9E+07	1.6E+07	8.6E+07	2.0E+06	<	<	3.0E+05	<	<	3.9E+07	1.6E+07	8.6E+07
	Chrysotile		0.15	3.1E+07	1.2E+07	7.0E+07							3.1E+07	1.2E+07	7.0E+07
	Amosite		0.15	7.8E+06	3.9E+06	1.6E+07							7.8E+06	3.9E+06	1.6E+07
59	88,90 [b]	HS-2	0.31	7.9E+06	7.9E+06	5.9E+06	6.0E+07	3.7E+07	3.6E+07	1.8E+07	1.1E+07	1.1E+07	1.8E+07	1.9E+07	1.7E+07

NOTES: All asbestos structures observed in all samples except Sample 76 (the soil component of HS-6) are chrysotile.

[a] Concentrations of asbestos structures in Sample 76 are both chrysotile and amphibole, which are presented both separately and combined. The majority of the putative chrysotile structures in Sample 76 do not exhibit a clear diffraction pattern suggesting that they may have been subjected to high heat. Regardless, the structure counts and concentrations for chrysotile that are presented in the table reflect total chrysotile structures (confirmed and putative combined) See additional discussion in text.

[b] The sample pairs: (88 and 90) and (98 and 100) are duplicate splits of the ACM components from HS-2 and HS-6, respectively and are averaged here.

D. Wayne Berman, Aeolus, Inc.

TABLE 7:
MATERIALS HANDLING (EXCAVATION, LOADING, AND DUMPING)
RECONCILED EQUATIONS FOR ESTIMATING PM_{10} EMISSIONS FROM MATERIALS HANDLING

Dust Model:

$E_{hnd} = 0.0016(Q_1)(k)(R_M)(U/2.2)^{1.3}/(M/2)^{1.4}$

Source: U.S. EPA (2002)
Rating: A — As long as applied when moisture content < 5%, silt content < 19%, and wind speed < 6.7 m/s.

where:

E_{hnd}	is the emission factor (gPM_{10}/sec)
k	is the particle size multiplier (unitless)
R_M	is the rate at which materials are handled (Mg/hr), which is added to the equation to convert from kg/Mg to kg/hr.
U	is the wind velocity (m/sec)
M	is the moisture content (mass %)
Q_1	is a conversion factor equal to 1000/3600 that is added to the equation to convert kg/hr to g/sec

Note that, although silt content does not appear explicitly, it was considered during development of the Equation.

Modifications:

The model is modified to convert it for use to predict asbestos emissions.

Although it would also be useful to modify this model to address silt content explicitly, the required background work has not been completed.

$E_{Ahnd} = 0.0016R_{a/d}(Q_1)(k)(R_M)(U/2.2)^{1.3}/(M/2)^{1.4}$

where:

E_{Ahnd}	is the asbestos emission factor (s/sec)
$R_{a/d}$	is the concentration of asbestos in source material, measured as the ratio of asbestos structures per mass of respirable dust (s/g_{PM10}) per the Superfund Method

RECONCILED EQUATIONS RELATING MATERIALS HANDLING AND EXPOSURE CONCENTRATIONS

<u>Exposure Point Concentrations Estimated at Receptor</u>

$C_{asb} = [0.0016R_{a/d}(Q_1)(Q_2)(k)(R_M)(U/2.2)^{1.3}/(M/2)^{1.4}]*\{1/[w_{cp}*h*U]\}$

where:

C_{asb}	is the exposure point concentration of asbestos (s/cm^3)
w_{cp}	is thre cross-wind width of the mixing box in which receptors are exposed (m)
h	is the height of the mixing box in which receptors are exposed
Q_2	is a factor (10^{-6}) to convert s/m^3 to s/cm^3.
	and all other parameters have been previously defined

Simplified:

$C_{asb} = [(1.47 \times 10^{-10})R_{a/d}(R_M)(U)^{1.3}/(M)^{1.4}]*\{1/[w_{cp}*h*U]\}$

Coeff Calc: 1.47292E-10

D. Wayne Berman, Aeolus, Inc.

TABLE 8:
MODEL DEVELOPMENT FOR DISTURBANCES ON UNPAVED SURFACES

RECONCILED EQUATIONS FOR ESTIMATING PM10 EMISSIONS FROM DISTURBANCE OF UNPAVED SURFACES

Dust Model:

$$E_{unp} = [5.9k(s/12)(S/30)(W/3)^{0.7}(w/4)^{0.5}/(M/0.2)^{0.3}]$$

Source: U.S. EPA 1985

Rating: A

However, because we are using this model for estimates on "vehicles" outside of the mass range over which it was tested, the quality rating for emissions estimates should likely be dropped to "B" or even "C" in this study.

where:

E_{unp}	is the emission factor (lbs_{PM10}/VMT)
VMT	is vehicle miles traveled
k	is the particle size multiplier (unitless)
s	is the silt content (wt %)
S	is the vehicle velocity (mph)
W	is the vehicle weight (tons)
w	is the mean number of wheels on the vehicles (#)
M	is the moisture content (wt %)

CONVERSION TO METRIC:

Metric Dust Model:

$$E_{unp} = [1.7k(s/12)(S/48)(W/2.7)^{0.7}(w/4)^{0.5}/(M/0.2)^{0.3}]$$

where:

E_{unp}	is the emission factor (kg/VKT)
	Note that the coefficient of the equation was also converted:
	5.9 lbs/VMT* (0.45 kg/lb)*(0.62 VMT/VKT) = 1.7 kg/VKT. Note: VKT = vehicle km traveled.
k	is the particle size multiplier (unitless)
s	is the silt content (wt %)
S	is the vehicle velocity (km/hr)
	Note that the denominator of the velocity term was also converted: 30 mph = 48 kph.
W	is the vehicle weight (Mg)
	To convert the denominator of the weight term, note: 3 tons = 2.7 Mg.
w	is the mean number of wheels on the vehicles (#)
M	is the moisture content (wt %)

D. Wayne Berman, Aeolus, Inc.

TABLE 8: (cont.)
MODEL DEVELOPMENT FOR DISTURBANCES ON UNPAVED SURFACES

MODIFICATIONS:

The model is modified to convert it for use to predict asbestos emissions per time and to account for effects of vegetative cover:

$E_{Aunp} = R_{a/d}*[1.7k(Q_1)(s/12)(S^2/48)(W/2.7)^{0.7}(w/4)^{0.5}/(M/0.2)^{0.3}][Tf + (1-Tf)(Vf)]$

where:

E_{Aunp}	is the asbestos emission factor: the rate of release of asbestos structures (s/sec)
Q_1	is a conversion factor equal to 1000/3600 that is added to the equation to convert kg/hr to g/sec
$R_{a/d}$	is the concentration of asbestos in source material, measured as the ratio of asbestos structures per mass of respirable dust (s/g_{PM10})
T_f	is the fraction of time spent on bare ground (vs. vegetated ground)
V_f	is the emission reduction factor for activities on vegetated (vs. bare) ground

Note also that the vehicle speed, S, has been squared in this version of the equation to convert to g/hr from g/VKT (g/hr = g/VKT * VKT/hr) where VKT is simply vehicle kilometers traveled. Thus, for a single vehicle (as in this application) VKT/hr = km/hr.

RECONCILED EQUATIONS RELATING EMISSIONS FROM SURFACE DISTURBANCE

Exposure Point Concentrations Estimated at Receptor

$C_{asb} = R_{a/d}*[1.7k(Q_1)(Q_2)(s/12)(S^2/48)(W/2.7)^{0.7}(w/4)^{0.5}/(M/0.2)^{0.3}][1/[w_{cp}*h*U][Tf + (1-Tf)(Vf)]$

where:

C_{asb}	is the concentration of asbestos in air (s/cm^3)
w_{cp}	is thre cross-wind width of the mixing box in which residents are exposed (m)
h	is the height of the mixing box in which residents are exposed
U	is the wind velocity or the velocity of the vehicle in stationary air (m/sec).
Q_2	is the conversion factor equal to 10^{-6} to convert from s/m^3 to s/cm^3.
	and all other parameters have been previously defined

Simplified:

$C_{asb} = (4.42 \times 10^{-11})*R_{a/d}*[(s)(S^2)(W)^{0.7}(w)^{0.5}/(M)^{0.3}][1/[w_{cp}*h*U][Tf + (1-Tf)(Vf)]$

Est of coefficient: 4.41689E-11

D. Wayne Berman, Aeolus, Inc.

TABLE 9:
MODEL DEVELOPMENT FOR DISTURBANCES ON DURING ROTOTILLING

RECONCILED EQUATION FOR ESTIMATING PM10 EMISSIONS DURING ROTOTILLING

Dust Model:

$E_{rot}=Q_3*k*[1.4*s*[(S/Q_4*5.5)]/(PE/50)^2]$ Source: Cowherd et al. 197 (P. 67)

where: Rating: ??

E_{rot}	is the emission factor for rototilling (g_{PM10}/sec)
s	is the silt content (wt %)
S	is the rototiller velocity (km/hr)
Q_4	is a conversion factor (=1.61 kmph/mph) to convert the reference velocity of 5.5 mph to kmph.
PE	is the Thornswaite PE index (unitless)
Q_3	is a conversion factor (derived as described below) to convert lb/acre to g/sec
k	is the particle size multiplier (unitless)
	Note that k was added to the equation to convert predictions of total suspended particulate to PM_{10}

Derivation of Q_3:

It is the product of g/lb and acres/sec

g/lb = 454

acres/sec = 6.73E-5, which is derived as follows:

Assume a rototiller cuts an effective swath of	1	ft	
The side of an acre is	208.7	ft	
Thus, the number of passes required to cover an acre is	208.7		=208.7/1
Thus, the total number of ft traversed to till an acre is	4.36E+04	ft	$=(208.7)^2$
The speed of a rototiller is assumed to be half walking speed	2.93E+00	ft/s	=2 mph
Thus, the time required to till an acre is	1.48E+04	s/acre	=4.36E+04/2.93
Thus, the rate of rototilling is	6.73E-05	acre/s	=1/1.48E+04

Thus, Q_3 = 0.031

Modifications:

The model is modified to convert it for use to predict asbestos

$E_{Arot}=R_{a/d}*Q_3*k*[1.4*s*(S/8.9)/(PE/50)^2]$

where:

E_{Arot}	is the concentration of asbestos in air (s/m^3)
$R_{a/d}$	is the concentration of asbestos in source material, measured as the ratio of asbestos structures per mass of respirable dust (s/g_{PM10})

All other parameters have been previously defined.

RECONCILED EQUATIONS RELATING AIRBORNE EXPOSURE CONCENTRATIONS TO CONCENTRATIONS IN THE BULK PHASE

Exposure Point Concentrations Estimated at Receptor

$C_{asb}=R_{a/d}*Q_3*Q_2*k*[1.4*s*(S/8.9)/(PE/50)^2][1/(w_{cp}*h*U)]$

where:

C_{asb}	is the exposure point concentration of asbestos (s/cm^3)
w_{cp}	is the cross-wind width of the mixing box in which receptors are exposed (m)
h	is the height of the mixing box in which receptors are exposed (m)
U	is the wind velocity of the rototiller in stationary air (m/sec)
Q_2	is the conversion factor equal to 10^{-6} to convert from s/m^3 to s/cm^3

All other parameters have been previously defined

Simplified:

$C_{asb}=(1.5E-08)*R_{a/d}[s*(S/8.9)/(PE/50)^2][1/(w_{cp}*h*U)]$

Est of coefficient: 1.5E-08

D. Wayne Berman, Aeolus, Inc.

TABLE 10:

MODEL DEVELOPMENT TO ESTIMATE EXPOSURE DURING HANDLING OF ACM

RECONCILED EQUATION FOR ESTIMATING PM10 EMISSIONS DURING HANDLING OF ACM

Dust Model:

$E_{ACM}=M_{ACM}*F_{CRMB}*F_{resp}/T_{event}$

Source: Developed ab initio

Rating: ??

where:

E_{ACM}	is the emission factor for dust during handling of ACM (g_{PM10}/sec)
M_{ACM}	is the Mass of ACM handled during a single event (g)
F_{CRMB}	is the fraction of ACM that is crumbled or abraded during a single event ($g_{crumbled}/g_{handled}$)
F_{resp}	is the fraction of crumbled or abraded material that becomes fine enough to be respirable ($g_{PM10}/g_{crumbled}$)
T_{event}	is the time over which the activity occurs (seconds)

Derivation of Input Factors:

Scenario:		Assumed Characteristics of ACM Handled				
Assume kids handle a piece of		Metric		English[a]		
ACM like a piece of challk. Thus,	Length	15.24	cm	6	in	This appears to be a convenient
the ACM will be abraded against	Diameter	3.81	cm	1.5	in	size for children to handle for
pavement and some fraction of the	Volume	174	cm3	10.60	in3	scenario proposed
material will become airborne.	Density	2.2	g/cm3	typical value for these materials		
Moreover, some fraction of the	M_{ACM}	382	g	=volume*density		
material that becomes airborne	F_{CRMB}	10%	%	THIS IS AN EDUCATED ESTIMATE THAT APPEARS REASONABLE ON AVERAGE		
will be abraded suffciently to	F_{resp}	2%	%	THIS ESTIMATE IS THE LEAST CERTAIN VALUE OF THIS CALCULATION[a]		
become respirable.	T_{event}	3600	sec	One hour (3600 sec) is a conservative estimate of the time per eventb		

Modifications:

The model is modified to convert it for use to predict asbestos

$E_{Asb}= R_{a/d}*M_{ACM}*F_{CRMB}*F_{resp}/T_{event}$

where:

E_{Asb}	is the asbestos emission factor: the rate of release of asbestos structures (s/sec)
$R_{a/d}$	is the concentration of asbestos in source material, measured as the ratio of asbestos structures per mass of respirable dust (s/g_{PM10})

All other parameters have been previously defined.

RECONCILED EQUATIONS RELATING AIRBORNE EXPOSURE CONCENTRATIONS TO CONCENTRATIONS IN THE BULK PHASE

Exposure Point Concentrations Estimated at Receptor (two scenarios considered)

Box Dispersion Model

In this case, a box is constructed around the active area of handling and the breathing zone of the handler. Asbestos is then released into the box at the rate predicted by the emission model and mixes with air entering the box due to local wind. Air within the box is assumed to be well mixed.

$C_{asb}=R_{a/d}*Q_2*[M_{ACM}*F_{CRMB}*F_{resp}/T_{event}][1/(w_{cp}*h*U)]$

where:

C_{asb}	is the exposure point concentration of asbestos (s/cm^3)
w_{cp}	is the cross-wind width of the mixing box in which receptors are exposed (m)
h	is the height of the mixing box in which receptors are exposed (m)
U	is the local wind velocity (m/sec)
Q_2	is the conversion factor equal to 10^{-6} to convert from s/m^3 to s/cm^3

All other parameters have been previously defined

Simplified:

$C_{asb}= (2.12E-10)*R_{a/d}*[1/(w_{cp}*h*U)]$ Est of coefficient: 2.12E-10

NOTES

[a] A laboratory simulation is recommended to evaluate this guesstimate

[b] One hour is about half of the total time estimated that children spend outdoors daily (U.S.EPA 1997). Thus, this estimate is conservative in a health protective sense because it assumes that ACM will be handled for fully half of the time that a child spends outdoors.

D. Wayne Berman, Aeolus, Inc.

TABLE 11:

EMISSION AND EXPOSURE MODELS FOR CONSTRUCTION-RELATED ACTIVITIES AT THE NORTHRIDGE ESTATES SITE, KLAMATH FALLS, OREGON

Excavation

The following emission factor is for a bulldozer but emissions should be similar for other types of equipment used for excavation:

$E_{exc} = (Q_1)*0.75*0.45(s)^{1.5}/(m)^{1.4}$ — Source: U.S. EPA 1989, pp 133 modified per: Eqn E-22, U.S. EPA 2002

where:

- E_{exc} is the emission factor (kg/sec)
- s is the silt content (mass %)
- m is the moisture content (mass %)
- Q_1 is a conversion factor equal to 1000/3600 that is added to the equation to convert kg/hr to g/sec

Note that the factor "0.75" is a scaling factor designed to convert the model to estimate emissions of PM_{10} rather than particles <15 um in diameter.

Grading

The following emission factor is reported as general for earthmoving.

$E_{grd} = 1.2*Q_1*(S/2)$ — Source: Cowherd et al. 1988, pp 5-3

where:

- E_{grd} is the emission factor (kg/sec)
- S is an estimate of the vehicle speed, which assumed to be half that of a transport truck[a]. This is needed to convert kg/km driven to kg/sec.
- and all other parameters have been previously defined.

Modifications

Both models are modified in an identical manner to convert them to predict asbestos rather than dust emissions.

$E_{asbx} = R_{a/d}*E_{xxx}$

where:

- E_{asbx} is the asbestos emission factor for the activity "x" (s/sec)
- $R_{a/d}$ is the concentration of asbestos in source material, meaured as the ratio of asbestos structures per mass of respirable dust (s/g_{PM10}) per the Modified Elutriator Method
- E_{xxx} is the corresponding dust emission model for either of the specific activities prresented above

RECONCILED EQUATIONS RELATING MATERIALS HANDLING AND EXPOSURE CONCENTRATIONS

<u>Exposure Point Concentrations Estimated at Receptor</u>

$C_{asbx} = R_{a/d}*(Q_2)[E_{xxx}]*\{1/[w_{cp}*h*U]\}$

where:

- C_{asbx} is the exposure point concentration of asbestos for the specific activity "x" (s/cm^3)
- w_{cp} is thre cross-wind width of the mixing box in which receptors are exposed (m)
- h is the height of the mixing box in which receptors are exposed
- Q_2 is a factor (10^{-6}) to convert s/m^3 to s/cm^3.
- and all other parameters have been previously defined

Simplified:

For bulldozer excavation:

$C_{asb} = (9.38E-8)*R_{a/d}*[(s)^{1.5}/(m)^{1.4}]*\{1/[w_{cp}*h*U]\}$ — Coeff Calc: 9.38E-08

For grading:

$C_{asbx} = (1.67E-07)*R_{a/d}*[S]*\{1/[w_{cp}*h*U]\}$ — Coeff Calc: 1.67E-07

D. Wayne Berman, Aeolus, Inc.

TABLE 12:

EMISSION AND EXPOSURE MODELS FOR CONSTRUCTION-RELATED TRANSPORT ON UNPAVED SURFACES AT THE NORTHRIDGE ESTATES SITE, KLAMATH FALLS, OREGON

Onsite Transport

The following emission factor is reported as general for vehicles traveling over unpaved surfaces

$E_{trn} = 732.9*(s/12)^{0.8}(W/3)^{0.4}(M_{dry}/0.2)^{0.3}(365-p)/365$ — Source: Eqn. E-18, U.S. EPA 2002

where:

E_{trn}	is the emission factor (g/VKT)
s	is the silt content (mass %)
W	is the average weight of the vehicle (Mg or metric tons)
M_{dry}	is the moisture content under dry conditions (mass percent)
p	is the average number of days per year with > than 0.254 mm precipitation

Exposure Point Concentrations Estimated at Receptor

$C_{OT} = F_D[(E_{tm}*\Sigma VKT)/(T_{proj}*A_R)]/(Q/C)$ — Source: U.S.EPA 2001, adapted from Equation E-18, Appendix E.

where:

C_{OT}	is the average concentration of dust generated over the construction area (kg/m^3)
F_D	is the dispersion correction factor (unitless)
ΣVKT	is the total number of vehicle km traveled over the course of the project
T_{proj}	is the total time over which construction will occur (s)
A_R	is the surface area of the contaminated road segment used for hauling (m^2)
Q/C	is the dispersion factor employed in the U.S. EPA Guide

Note:

For construction projects lasting substantially more than 10's to 100's of hours, F_D approaches a constant value equal to 0.1852.

Using the Equation provided for estimating "Q/C" (Equation E-19, U.S. EPA 2002), incorporating the constants appropriate for Las Vegas, and given an area for the borrow pit of acres, the value used in this analysis for "Q/C" is

$Q/C = A \times EXP[(\ln(A_s)-B)^2/C]$			13.02572
A	12.9351		
B	5.7383		
C	71.7711		
As	1.53E+02	acres	areal extent of site surface contamination

Estimating Asbestos Exposure Concentrations

$C_{asb} = R_{a/d}*C_{OT}$

where:

C_{asb}	is the airborne concentration of asbestos (s/cm^3)
$R_{a/d}$	is the concentration of asbestos meausred in source material (s/g$_{PM10}$)
C_{OT}	is the concentraion of dust in air (g$_{PM10}$/cm^3)

D. Wayne Berman, Aeolus, Inc.

TABLE 13:
VARIABLES EMPLOYED IN EQUATIONS USED TO ESTIMATE ASBESTOS EXPOSURES
ASSOCIATED WITH DUST GENERATING ACTIVITIES OF INTEREST PERFORMED IN SOILS OR CONTAMINANTED FILL

		Typical Values												
Variable	Symbol	Walking	Running	Bicycling	ATV Riding	Rototilling	Child-play or Gardening	Handling ACM	Bulldozer Excavation	Loading or Dumping	Grading	Transport (SSL)	Units	Comments
Particle Size Multiplier	k	0.35	0.35	0.35	0.35	0.35	0.35			0.35			unitless	For PM_{10} size fraction, defined in citatations to models
Moisture Content	M	0.2	0.2	0.2	0.2		2		2	2		0.2	wt%	Reasonable worst case minimum
Number of wet days/yr	p											90	unitless	Site-specific, conservative estimate from Exhibit 5-2 of U.S.EPA 2001
Thornswaite PE index	PE					32							unitless	Site-specific , conservative estimate from Figure 4-2 of U.S.EPA 1985
Silt Content[a]	s	38	38	38	38	38	38		38	38	38	38	wt%	Upper end of range of measured values
Gross Vehicle Speed	S	6	9.7	16	30	3.2					24	48	km/hr	Reasonable worst case maximums
Asbestos Concentration in Dust	$R_{a/d}$	**TBD**	**TBD**	**TBD**	**TBD**	**TBD**	**TBD**	**TBD**	**TBD**	**TBD**	**TBD**	**TBD**	s/gPM_{10}	Site-specific values are selected/presented in the following discussion
Mass materials handling rate	R_M						0.125			14			Mg/hr	Typical values for activities listed
Wind Velocity	U	3.0	3.0	4.4	8.3	3.0	3.0	3.0	3.0	3.0	3.0	3.0	m/sec	(6.7 mph = 3 m/s)[c] Greater of mean for area or activity-specific velocity
Gross Vehicle Wt	W	0.073	0.073	0.09	0.45							20	Mg	Typical values for activities listed (see text)
No. of vehicle wheels[b]	w	2.4	2.4	0.17	4								#	Estimated as indicated in text
Emission Reduction Factor	V_f	0.01	0.01	0.01	0.01								unitless	Worst case values for effect of vegatative cover
Fraction of Time on Bare Ground	T_f	0.5	0.5	0.5	0.5								unitless	Worst case values
Dispersion Box Dimensions:														
Width for continuous proximity	w_{cp}	3	3	3	10	3	0.5	0.5	5	5	10		m	This is estimated based on the dynamics of exposure (see text)
Mixing Height	h	1.75	1.75	1.75	2	1.75	0.5	0.5	1.75	1.75	4		m	This is estimated based on the dynamics of exposure (see text)
SSL Transport Parameters														
For SSL Transport Model	Q/C											1.30E+01	g/m2-s/kg/m3	Location specific with Equation E-19, U.S.EPA 2002 (SSL Guide)
Dispersion Adjustment Factor	F_D											0.182	unitless	Recommended from U.S.EPA 2002 (SSL Guide)
Road Surface Area	A_R											5.07E+03	m^2	= Mean road width (assumed 15 ft) x Lroad
Number of Vehicle Km Traveled	VKT											5.54E+02	km	=V/proj*Lroad
Total Area of Project Site	A_s											1.53E+02	Acres	Assumed value is equal to footprint area of the studied properties
Loads per Project	V/proj											500	unitless	Assume 2 loads per day over 1 year of project
Length of Construction Site Road	Lroad											1.11E+00	km	Assumed: 2x the distance from center to edge of square site x loads/proj
Active Project Period	T											7.20E+06	s	This is the number of seconds in an occupational year.

NOTES:

Parameters for which no values are provided are not applicable to the specific model indicated at the head of the column
For pathways involving walking, running, and bicyciling riding, exposure estimates are actually for a person following immediately behind a leader (see text)
For pathways involving moving bodies, the minimum wind velocity would be the greater of the actual wind velocity or the velocity of the body.
For pathways involving activities conducted under full dust control, M = 9% (see text).

[a] For a detailed discussion of silt content, see Appendix D.
[b] For a detailed discussion of the derivation of the values used for number of wheels, see Appendix C.
[c] Regarding wind speed, 6.7 mph is the annual mean reported for Klamath Falls.

EQUATION TO DETERMINE Q/C (USEPA 2002)

$Q/C = A \times EXP[(\ln(A_s)-B)^2/C]$			13.026
A	12.9351		
B	5.7383		
C	71.7711		
As	1.53E+02	acres	(see above)

D. Wayne Berman, Aeolus, Inc.

TABLE 14:

ESTIMATED DUST EMISSION RATES AND AIRBORNE DUST CONCENTRATIONS CREATED IN ASSOCIATION WITH THE INDICATED ACTIVITY AT THE NORTH RIDGE ESTATES SITE, KLAMATH FALLS, OREGON

Activity	Instantaneous Emission Rate (kg/sec)	Instantaneous Dust Concentration (mg/m^3)	Time Averaged Dust Concentration (mg/m^3)	Instantaneous PEF $1/(kg/m^3)$
Residential Pathways				
Walking	2.4E-05	7.8E-01	2.7E-02	1.3E+06
Running	6.4E-05	2.0E+00	5.0E-02	4.9E+05
Bicycling	5.3E-05	1.2E+00	4.0E-02	8.6E+05
Gardening	2.9E-08	3.9E-02	7.3E-04	2.6E+07
Playing in Soil	2.9E-08	3.9E-02	9.9E-04	2.6E+07
Combined Gardening and Play	2.9E-08	3.9E-02	1.3E-03	2.6E+07
Playing w ACM	2.1E-07	2.8E-01	3.5E-04	3.5E+06
Rototilling	5.0E-04	3.2E+01	2.6E-02	3.2E+04
ATV Riding	2.8E-03	8.5E+00	8.3E-02	1.2E+05
Worker Pathways				
Bulldozer Excavation	8.3E-03	3.2E+02	1.0E+00	3.2E+03
Loading/Dumping	3.3E-06	1.2E-01	4.0E-04	8.1E+06
Grading	4.0E-03	3.3E+01	1.1E-01	3.0E+04
Transport (SSL)	**3.0E+03**	6.3E-01	2.1E-03	1.6E+06
Full Dust Control		**5.0E+00**	1.6E-02	2.0E+05
Worker Pathways Remediation Scenario				
Bulldozer Excavation	8.3E-03	3.2E+02	1.7E-01	3.2E+03
Loading/Dumping	3.3E-06	1.2E-01	6.7E-05	8.1E+06
Grading	4.0E-03	3.3E+01	1.8E-02	3.0E+04
Transport (SSL)	**3.0E+03**	6.3E-01	3.4E-04	1.6E+06
Full Dust Control		**5.0E+00**	2.7E-03	2.0E+05
Offsite Impact to Residents				
Combined Construction	3.0E+03	6.3E-01	2.1E-03	1.6E+06
Remediation Scenario	3.0E+03	6.3E-01	3.4E-04	1.6E+06

Note:

Due to the manner in which these are estimated, concentrations estimated for residential scenarios should not be summed. Rather, each indvidual estimate is a "worst case" in the sense that it assumes a person spends all of the time that they devote to outdoor activities doing the one activity estimated.

D. Wayne Berman, Aeolus, Inc.

TABLE 15:
ESTIMATED DURATION AND FREQUENCY OF EXPOSURE FOR ACTIVITIES EVALUATED AT THE NORTH RIDGE ESTATES SITE, KLAMATH FALLS, OREGON

Activity		Frequency (hrs/day)	Frequency (days/year)	Fraction Year	Duration (years)	Fraction Lifetime	Reference	Comments
Residential Pathways								
	Walking	2	350	0.080	30	0.034	a	On unpaved surfaces in neighborhood
	Running	2	250	0.057	30	0.024	b	On unpaved surfaces in neighborhood
	Bicycling	2	350	0.080	30	0.034	a	On unpaved surfaces in neighborhood
	Gardening	1.5	350	0.060	22	0.019	a	On Property
	Child Digging	5.6	350	0.224	8	0.026	a	On Property
	Combined Gardening and Play	2	350	0.080	30	0.034	a	On Property
	Playing w ACM	1	50	0.006	15	0.001	b	Not Applicable
	Rototilling	2	5	0.001	50	8.2E-04	c	On Property
	ATV Riding	4	50	0.023	30	0.010	b	On unpaved surfaces in neighborhood
Worker Pathways								
	Bulldozer Excavation	8	250	0.228	1	0.003	1 yr project	On unpaved surfaces in neighborhood
	Loading/Dumping	8	250	0.228	1	0.003	1 yr project	On unpaved surfaces in neighborhood
	Grading	8	250	0.228	1	0.003	1 yr project	On unpaved surfaces in neighborhood
	Transport (SSL)	8	250	0.228	1	0.003	1 yr project	On unpaved surfaces in neighborhood
	Full Dust Control	8	250	0.228	1	0.003	1 yr project	On unpaved surfaces in neighborhood
Worker Pathways Remediation Scenario								
	Bulldozer Excavation	8	250	0.228	0.17	0.001	2 mo project	On unpaved surfaces in neighborhood
	Loading/Dumping	8	250	0.228	0.17	0.001	2 mo project	On unpaved surfaces in neighborhood
	Grading	8	250	0.228	0.17	0.001	2 mo project	On unpaved surfaces in neighborhood
	Transport (SSL)	8	250	0.228	0.17	0.001	2 mo project	On unpaved surfaces in neighborhood
	Full Dust Control	8	250	0.228	0.17	0.001	2 mo project	On unpaved surfaces in neighborhood

Notes:
- a Exposure Factors Handbook (U.S.EPA 1997), convservative for activity
- b Professional Judgement
- c U.S.EPA 2001

D. Wayne Berman, Aeolus, Inc.

TABLE 16:
ESTIMATED ASBESTOS CONCENTRATIONS IN SOIL
AT THE NORTH RIDGE ESTATES SITE, KLAMATH FALLS, OREGON

	Bulk Concentrations		
	protocol	**%long**	**7402**
Type of Estimate	**(s/ugPM$_{10}$)**	**(s/ugPM$_{10}$)**	**(s/ugPM$_{10}$)**
CHRYSOTILE			
Mean of Composite Concentrations (w/o ACM)[a]	0.18	100%	0.18
95% UCL for mean of Composite Concentrations (w/o ACM)[b]	0.9	100%	0.9
Maximum of Composite Concentrations (w/o ACM)	2.0	100%	2.0
Maximum of Composite Concentrations (w ACM)	19	50%	7.2
Maximum of Hot Spot Concentrations (w ACM)	300	50%	130
Maximum Detected Concentration in ACM	6300	50%	2200
Mean of Detected Concentrations in ACM	770	50%	250
Concentration of Chrysotile Detected in Steampipe Insulation[c]	2400	35%	1100
AMOSITE			
Maximum of Hot Spot Amosite Concentrations (w ACM)	7.8	50%	16
Concentration of Amosite Detected in Steampipe Insulation[c]	24000	36%	14000

Notes:

"w/o ACM" means that only the structures observed in the soil component are included in the determination of asbestos concentration in the sample

"w ACM" means that contributions of structures observed in both soil and ACM components are included in the determination of asbestos concentration in the sample

"in ACM" means that this is the concentration of asbestos observed in the pure, isolated ACM component of the sample.

[a] Because only one (long) structure was observed in this sample, the fraction of long structures reported should not be considered reliable.

[b] Based on a Poisson distribution, the upper 95% confidence limit for a mean of one structure is 5 structures (rounded to the nearest integer).

[c] Based on TEM measurements recently reported for a composiste sample of steampipe insulation (MAG ACM) recovered from the site in spring of 2004.

D. Wayne Berman, Aeolus, Inc.